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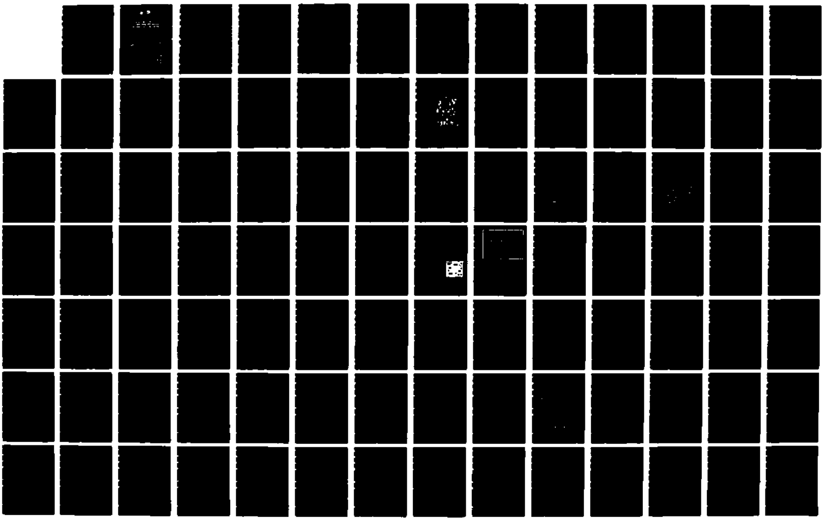

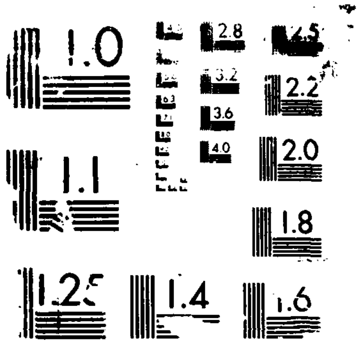

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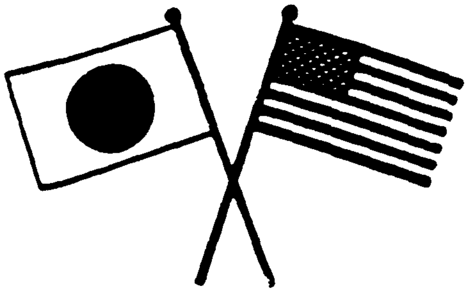
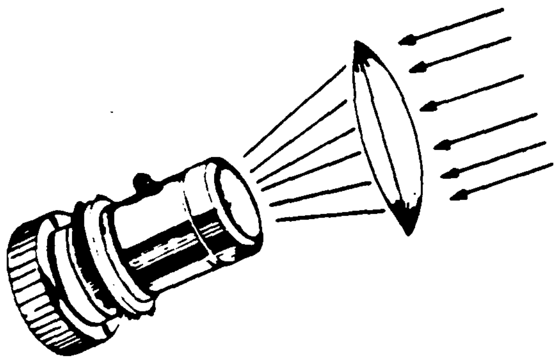
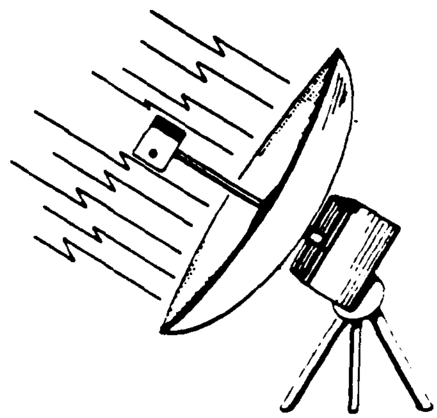


ELECTRO-OPTICS AND MILLIMETER-WAVE TECHNOLOGY IN JAPAN

FINAL REPORT OF DOD TECHNOLOGY TEAM

MAY 1987





OFFICE OF THE UNDER SECRETARY OF DEFENSE
(ACQUISITION) RESEARCH AND
ADVANCED TECHNOLOGY

DR. JOHN M. MacCALLUM, JR.
TEAM LEADER

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This report is DOD's ongoing commitment to support international defense cooperation. The Office of the Under Secretary of Defense for Research and Engineering (OUSDRE) authorized the Electro-Optic and Millimeter Wave (EO/MMW) Technology Team to return to Japan to further develop the concept of data exchange and cooperation with Japan in development of these technologies. The team led by Dr. John M. MacCallum, Jr. (OUSDRE/R&AT/MST) revisited Japan from 18 through 29 August 1986. The first EO/MMW Team, also led by Dr. MacCallum, visited Japan in July 1984 and again in April 1985. A detailed report, (DTIC AD-A-157376), based on the team's findings, was published. A summary of these findings may be found in Appendix A.

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FOR FINAL REPORT OF
DOD TECHNOLOGY TEAM
ON
ELECTRO-OPTICS AND MILLIMETER-WAVE
TECHNOLOGY IN JAPAN
May 1987
PROVIDED BY JAPAN

PAGE	LINE	COMMENTS
ES-7	31	"Boeing 757 and 767" should be changed to Aircraft." (Rationale) According to the explanation of JAE to TAT, the referred color falt panel displays are developed not for Boeing 757 and 767, but for future aircraft.
1-3	8	"systems" should be corrected as Systems".
2-2	24	"seismographic project" should be corrected as "experiment".
2-6	9	"A significant amount of resources were dedicated to this project." should be deleted.
2-10	3	"and SAW" should be deleted.
	13	"UV" should be corrected as "DUV".
2-22	8	"and 90°" should be corrected as "90°, and 180°".
2-35	1	"30 MHz, making it suitable for high definition TV applications" should be corrected as "high speed analog and digital signals, making it suitable for high definition TV applications (30MHz)".
2-39	28	"Both 10k and 26k gate arrays are under development." should be deleted.
2-40	8	"Researchers are currently using molecular beam epitaxy (MBE)." should be deleted.
2-42	17	"for U.S. companies." should be deleted.

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ELECTRO-OPTICS/MILLIMETER WAVE TECHNOLOGY IN JAPAN

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

Background

As part of its ongoing commitment to support international defense cooperation, the Office of the Under Secretary of Defense for Research and Engineering (OUSDRE) authorized the Electro-Optic and Millimeter Wave (EO/MMW) Technology Team to return to Japan to further develop the concept of data exchange and cooperation with Japan in development of these technologies. The team, led by Dr. John M. MacCallum, Jr. (OUSDRE/ R&AT/MST), revisited Japan from 18 through 29 August, 1986. The first EO/MMW Team, also led by Dr. MacCallum, visited Japan in July 1984 and again in April 1985. A detailed report, (DTIC #AD-A-157376), based on the team's findings, was published. A summary of these findings may be found in Appendix A. The objectives of this trip were to:

- Brief JDA, MITI, and Japanese industry on U.S. Government and industry responses and interests from previous EO/MMW Team efforts and visits.

- Conduct follow-up visits to Japanese industries in high interest areas (e.g., displays, radar modules, detectors, and fiber optics),

- Visit additional companies identified as conducting R&D of interest,

- Provide, wnere appropriate, technology briefings by team members, identifying specific areas of interest and potential applications and mechanisms for cooperation,

- Extend formal and informal invitations for Japanese counterparts, scientists, and engineers to come to visit U.S. facilities engaged in R&D in relevant technologies, and finally,

- Collect information to extend and update the EO/MMW report and recommend mechanisms to implement an ongoing, long-term technology exchange program.

The eight members of the team included:

Dr. John M. MacCallum, Jr. Team Leader OUSDRE	Dr. Barry E. Spielman Naval Reasearch Laboratory
Dr. Paul D. Travesky, Director Army Night Vision Electro-Optics Center	Mr. Martin L. Musselman Naval Research Laboratory
Dr. James F. Gibson Army Night Vision Electro-Optics Center	Mr. Richard L. Remski Air Force Wright Aeronautical Laboratories
Dr. Ken J. Ando Defense Advanced Research Project Agency	Mr. Mitchell B. Mellen B-K Dynamics, Inc. (Administrative Support)

Brief biographies are provided in Appendix B.

Four meetings were held with JDA and MITI personnel and seven Japanese companies were visited during this trip. Sony and OKI were first time visits by the team, while the other five, Mitsubishi Electric, Matsushita, Nippon Electric Company, Fujitsu, and Japan Aviation Electronics were revisits.

General Findings

During the course of this trip, a number of technology areas with particularly high potential for application in U.S. programs were identified. Figure ES-1 indicates Japanese technical areas with good potential for cooperation from both teams visits. Of special note from this trip were the observations that:

JAPANESE COMPANIES	AREAS OF INTEREST: MICROWAVE/ MILLIMETER WAVE TECHNOLOGIES				ELECTRO-OPTICS						FIBER OPTICS				DISPLAYS			MICRO-ELECTRONICS				OTHER		
	Devices and Components (SAWS)	MMICs	GaAs Devices	DBS Receivers/Sat Comm & Nav	Devices and Components	Semiconductor Lasers	Optical Storage	Visible Imagers	IR CCD/Imagers	Seekers	Devices and Components	Fiber Optic Gyros	Ring Laser Gyros	FO Communication Devices	High Resolution CRTs	EL/Plasma Panels	Liquid Crystal Displays	GaAs Digital ICs	Si Digital ICs (VLSI)	MOCVD/MBE R&D	Advanced Robotics	Signal Processing	Artificial Intelligence	JJ (SQUIDS)
FUJITSU			X	X			X		X		X			X		X	X	X	X	X				
HITACHI				X		X	X	X	X		X													
JAE												X	X			X	X							
MATSUSHITA	X		X	X		X	X	X			X				X	X						X		
MELCO	X		X	X			X	X	X		X				X			X						
NEC	X			X	X			X	X			X						X	X	X				
OKI	X	X	X			X					X			X		X			X	X	X			
SHARP	X			X		X	X	X			X			X		X	X							
SONY				X		X								X	X			X		X			X	
SUMITOMO	X		X			X					X	X								X				
TOSHIBA	X		X	X		X		X	X		X			X										
TRDI#1						X		X	X															
TRDI#3	X		X						X			X												

Figure ES-1

▨ COOPERATION POTENTIAL

Source: EO/MMW Team

- Japanese industries appear to be within 1-2 years of commercialization of magneto-optical erasable disk technology for mass storage applications.

- Several Japanese companies demonstrated hybrid and monolithic integration of optical and digital devices. This work, and interfacing of GaAs and silicon devices will enable the next generation of advanced electronics and electro-optics.

- Japanese industries continue to develop a base of gallium arsenide (GaAs) devices including high electron mobility transistors (HEMTs), large scale integration (LSI), metal semiconductor field effect transistors (MESFETs), power field effect transistors (FETs) which are comparable or ahead of U.S. work. Their approach of developing more generic devices rather than highly specialized circuits (as is done in the U.S.) has increased Japan's ability to produce devices at low cost and high volume.

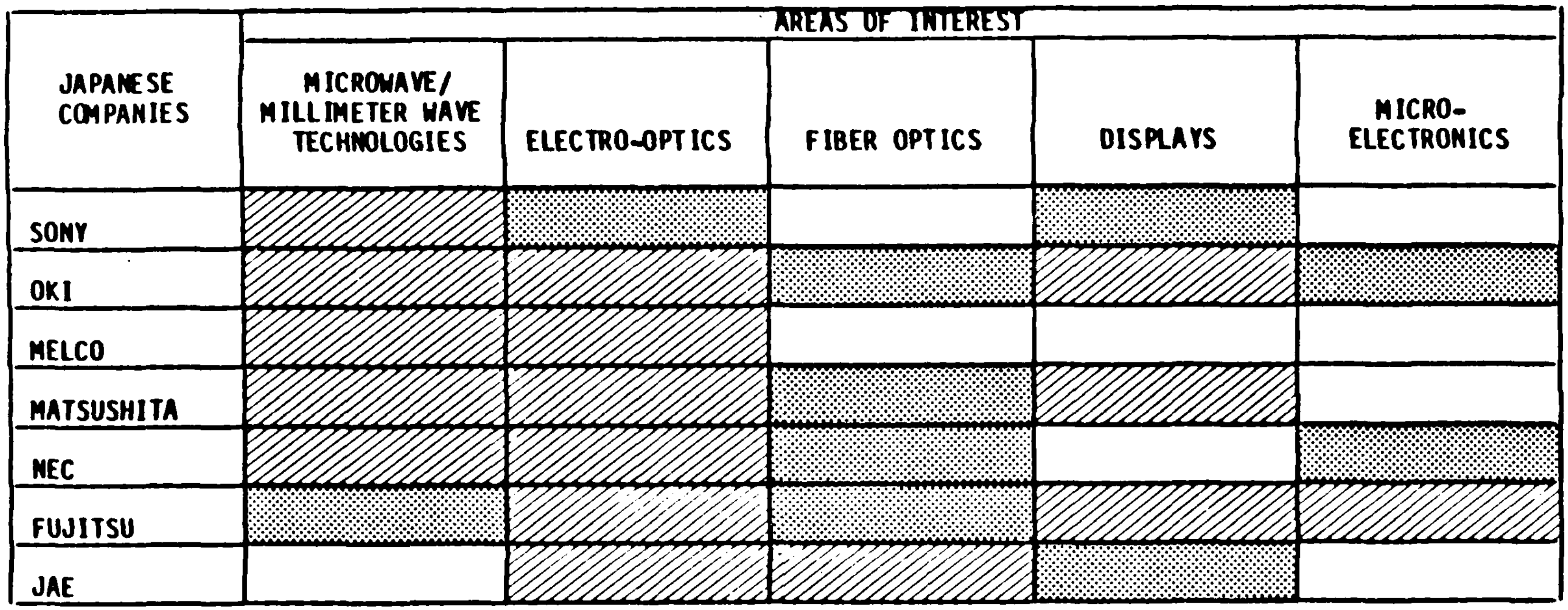
- Low cost, high production shutterable visible charge coupled device (CCD) imagers are state-of-the-art quality in Japan and could benefit U.S. military imaging applications. PtSi work was generally comparable to current U.S. efforts.

- The Japanese are slightly ahead of the U.S. in the variety of their research and development (R&D) of cathode ray tube (CRT), plasma display panel (PDP), and liquid crystal display (LCD) technologies and lead the U.S. in the commercialization and production of these devices.

Summary of Company Visits

The following paragraphs briefly summarize some of the technologies seen at the companies visited on this trip (see Figure ES-2).

- Sony demonstrated outstanding capabilities in video display technologies showing a 20" x 20" flat CRT designed for air traffic



= Exceptional Capability

= Demonstrated Capability

= Capability Not Discussed

Figure ES-2

MAJOR JAPANESE EO/MMW THRUSTS

Source: EO/MMW Team

control applications with 2048 x 2048 pixels, an 1800 foot-Lamberts high brightness Indextron monitor measuring 109 x 82 mm, and 19" color computer display monitors with 1280 x 1024 pixels. Sony researchers discussed a 50 GHz communication system. They also described work on a professional broadcast quality 53 gigabyte digital data recorder with a 118 Mbps recording rate, a digital coding/decoding scrambler for cable television (CATV) or Direct Broadcast Satellite (DBS) applications, and radio determination satellite service for Geostar and Global Positioning Satellite (GPS) development. Sony is currently pursuing research in semiconductors, optoelectronics, and magnetic and organic materials.

- OKI showed impressive electroluminescent, liquid crystal, and plasma display technologies, 800-900 MHz mobile radio telephone equipment using GaAs components, and optical fiber communication developments. OKI is engaged in state-of-the-art compound semiconductor work in GaAs expitaxial growth on Si by metal organic chemical vapor deposition (MOCVD). OKI is working vigorously on molecular beam epitaxy (MBE) and with .25 to .5 micron design rules in GaAs circuits they are strongly competing with U.S. silicon VHSIC type and super short gate length device efforts.

- MELCO described their work in defense-related electronic components (especially for missiles and fire control radars), space satellites, electro-optics and fiber optics, and short- and longrange laser work. Work of particular interest included their 94 GHz seeker head, 94 GHz components, X-band and K_A-band GaAs monolithic ICs, and some IRCCD work.

- Matsushita is almost totally commercial-consumer product oriented. They described a 10% improvement in fiber optic performance over the last two years, a 2.5 times improvement in pyroelectric detectors using $(PbLa)TiO_3$ rather than $PbTiO_3$, and claimed production of 300,000 GaAs chips per month for consumer products. These devices were primarily low noise amplifiers and mixers. Of particular interest

were high Q dielectric ceramics, high frequency (HF) surface acoustic wave (SAW) dispersive filters, GaAs microwave devices, and DBS receiver technology.

- NEC is one of Japan's largest electronic companies specializing in communications equipment, computer and industrial products, and home entertainment electronics. They are strongly involved in the integration of computers and communications. NEC described work on a shutterable visible CCD imager, 20 GHz HEMT devices with production yields of 30%, Indium doped liquid encapsulated Czochralski (LEC) GaAs substrates with 20 mV standard deviation on measured transistor threshold voltages across a 3 inch wafer, extensive monolithic microwave integrated circuits (MMICs), and digital GaAs integrated circuits (ICs).

- Fujitsu devotes 72% of their resources to computer technology, 16% on communications, and 12% on electron devices. There is extensive R&D work on Si (4 Mbit DRAMs) and GaAs (LSI and 4 Kbit SRAMs). The high electron mobility transistor was invented and developed at Fujitsu. New work on this device is continuing. Of particular interest is their opto-electronic integrated circuit work combining an avalanche photodiode (APD) and four FETs on the same substrate in a two-step process first growing the laser diode by liquid phase epitaxy (LPE), then the FETs by molecular beam epitaxy (MBE). Fujitsu is developing two different plasma display panels in 640 x 400 dot and 320 x 80 dot formats. They are also working on surface discharge, three color displays. Fujitsu leads other Japanese companies in Infra-red (IR) detector focal plane array development using mercury-cadmium-telluride (HgCdTe).

- Japan Aviation Electronics (JAE) works extensively on laser inertial navigation systems, laser gyros, and fiber optics gyros. They also demonstrated color flat panel displays which are being developed for Boeing 757 and 767 cockpit applications. The 5" x 5", 8 color displays have 120 dots/inch, weigh 7 kg and have .4" resolution touch switches.

Conclusions

This trip was very successful in that the EO/MMW Team has accomplished its mission of initiating dialog with the Japanese government and Japanese industries. This trip further established the dialog begun by the first team visit. More detailed technical information was gathered from companies previously visited and companies not visited before. The team found that a significant number of Japanese industries have ongoing R&D programs in EO and MWW related activities that are of interest to, and offer potential benefit for enhancing DoD programs. Preliminary analysis grouped these EO/MMW technologies into:

- INFORMATION PROCESSING, including fiber optics, television, displays, communications, and computers;
- BASIC MICROELECTRONICS, including GaAs devices and optoelectronics;
- SPACE APPLICATIONS, including ring laser and fiber optic gy-os; and
- AERONAUTIC APPLICATIONS, including radar altimeters, accelerometers, and various display and control technologies.

The Japanese are demonstrating impressive and rapid progress in these areas, particularly in transitioning R&D work into production and commercialization.

Each of the six objectives for this trip identified above were successfully met. Japanese government officials are aware of U.S. interests and have expressed their willingness to cooperate in establishing ongoing exchange in relevant EO/MMW technologies. With the distribution of the information gathered during the trip by this report, the last link in the chain will be formed with U.S. government and industry concerns.

1.0 U.S. - JAPANESE TECHNOLOGY TRANSFER COOPERATION

1.1 INTRODUCTION

Realizing the growing importance of state-of-the-art research and advanced technology to the development of current and future military systems, and the fact that the U.S. no longer leads in all areas, nor is the only source for all advanced technologies, the U.S. Government pursues a policy of international cooperation in research and development (R&D) of technologies with military applications. To this end in 1980, seeking to increase the scope of U.S. - Japanese cooperation, the U.S Department of Defense (DoD) and the Japanese Defense Agency (JDA) established the joint Systems and Technology Forum (S&TF). The S&TF seeks to facilitate cooperation between JDA and DoD in the research, development, production, and procurement of military equipment.

Following the announcement in 1983 that Japan would allow the export of military technology to the United State, notes were exchanged implementing the decision. As a result of this agreement, the Office of the Under Secretary of Defense for Research and Advanced Technolgy developed the concept for teams of U.S. scientists, representing the DoD, to identify U.S. needs and interests, research Japanese technology programs, and visit Japanese counterparts and facilities in selected disciplines to explore and assess the potential for cooperative programs of mutual benefit and interest.

1.2 BACKGROUND

The first Technology Team, as proposed by OUSDRE, was chartered to review Japanese programs in electro-optics (EO) and millimeter wave (MMW) technologies. The 11 members of the first team, led by Dr. John M. MacCallum of OUSDRE/R&AT/MST, were government and industry experts in these areas. After a series of preliminary meetings, this team went to Japan to visit research facilities and counterparts in July 1984. Figure 1 summarizes facilities and technologies from this visit. A detailed report, (DTIC #AD-A157376),

TRDI #1

- Lasers
- Visible Imagers
- Infrared Imagers
- Visible Night Vision Devices

NEC

- Field-Effect-Transistor (FET) Development
- Millimeter- and Micrometer-Wave Monolithic Integrated Circuits (ICs)
- Millimeter-Wave Diodes
- Electro-Optics
- Millimeter-Wave and Microwave Tubes
- Fiber-Optic Gyros

HITACHI

- Optical Disk Technology
- Semiconductor Lasers
- Optical Fiber Technology
- Fiber-Optic (FO) Data Links
- High-Resolution TV Cameras

FUJITSU

- Local Area Network (LAN) and Components
- Millimeter-Wave Doppler Radar
- IR CCD Imaging
- Phased-Array Antenna for Radar

MITSUBISHI

- 94 GHz Missile Seeker and Millimeter-Wave Components
- Optical Fire Control System
- Missile/Anechoic Chamber Simulator Facility
- Millimeter-Wave Radiometers
- Carbon Dioxide (CO_2) Lasers

TRDI #2

- Millimeter- and Micro-wave Devices
- Active Apertures
- Microwave Systems

TOSHIBA

- Gas Lasers
- Microwave and Millimeter-Wave Semiconductor Devices
- Direct Broadcast Satellite (DBS) Receivers
- Visible CCD
- GaAs Lasers for Optical Storage Disks
- Integrated Optic Spectrum Analyzer (IOSA)

SHARP

- DBS Receivers
- Visible Semiconductor Lasers
- Eraseable High Density Optical Storage

SUMITOMO

- GaAs Production Technology
- Optical Fiber Communications
- Fiber-Optic Gyro (FOG)

MATSUSHITA

- Optical Storage Disks
- Sensors
- High-Q, High-Dielectric-Constant Materials for Filter Miniaturization and Frequency Stabilization with Temperature
- DBS Downconverter Development and Production
- Optical Devices
- Optical Fiber Communication

Figure 1

SUMMARY OF FACILITIES AND TECHNOLOGIES
JULY 1984 JAPAN TRIP

Source: EO/MMW Team

based on the team's findings was written and approved for publication by the U.S. and Japan in April 1985. A summary of the findings from this report may be found in Appendix A. The report was widely distributed throughout the U.S. Government and industry. The report was translated by the Japanese and distributed by the JDA in Japan. From July through December 1985, the team received feedback on the report from U.S. industry and government specialists and identified 23 major areas of interest for cooperation (see Figure 2). In January 1986, the systems and Technology Forum (S&TF) was briefed on the team's findings and U.S. industries' responses. At the recommendation of the S&TF, a return trip to Japan was planned for later in the year.

In August 1986, Dr. MacCallum led a second group of all government experts (see Appendix B for biographies) on a follow-up visit to Japan. During the two week trip, two formal and two informal meetings were held with personnel from JDA and MITI and seven Japanese companies were visited (see Figure 3). Sony and OKI Electric were first time visits by the team, and the other five companies (MELCO, Matsushita, NEC, Fujitsu, and JAE) were revisits. This report presents information learned from this second trip to Japan, provides an overview of Japanese electro-optics (EO) and millimeter-wave (MMW) technologies, and draws conclusions about the potential for cooperation and technology transfer.

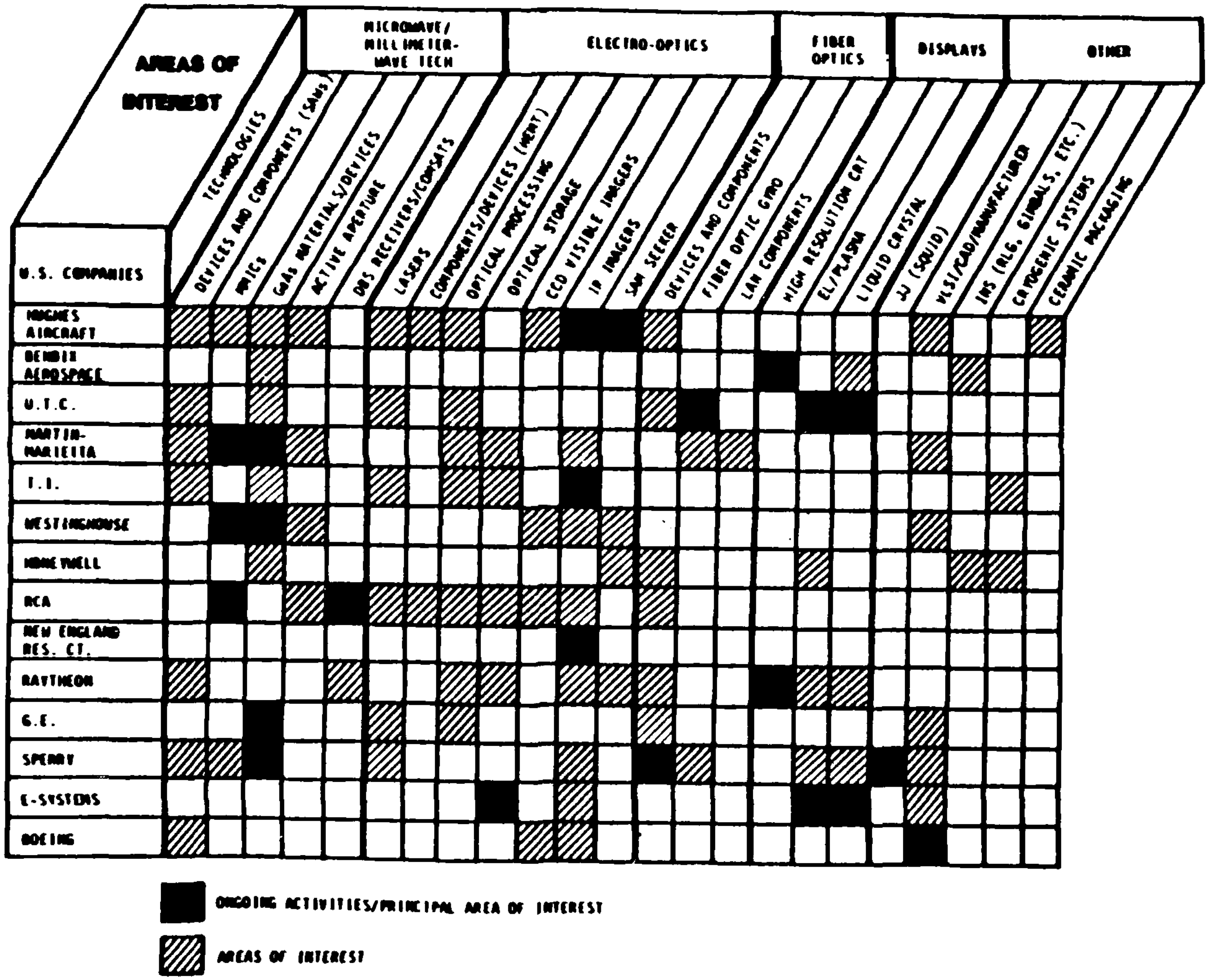


Figure 2

AREAS OF INTEREST FOR TECHNOLOGY COOPERATION

Source: EO/MMW Team

SONY

- Video Displays, HDTV
- Digital Data Recorder
- CATV/DBS Scrambler
- Radio Determination Equipment
- Opto-Electronics and Semiconductor Research
- Image Processing/Artificial Intelligence
- 50 GHz Communication System
- MOCVD Processing
- HIFET Devices
- Epitaxial YIG Filters
- Visible CCDs
- GaAs Superlattices

OKI ELECTRIC

- EL, LC, and Plasma Display Technologies
- Fiber Optic Components
- Radio Telephone Components
- Compound Semiconductor R&D - GaAs on SI
- Heterostructure, Bipolar and Field-Effect-Transistor (FET) Devices

MITSUBISHI

- 94 GHz Missile Seeker and Millimeter-Wave Components
- Optical Fire Control System
- Missile/Anechoic Chamber Simulator Facility
- X-Band and K_a Band GaAs Monolithic ICs
- Infra-Red Charge Sweep Device Development

MATSUSHITA

- Optical Storage Disks
- Sensors
- High-Q, High-Dielectric-Constant Materials for Filter Miniaturization and Frequency Stabilization with Temperature
- DBS Downconverter Development and Production
- Optical Devices
- Optical Fiber Communications

NEC

- Field-Effect-Transistor (FET) Development
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- Electro-Optics
- Millimeter-Wave and Microwave Tubes
- Fiber-Optic Gyros

FUJITSU

- Local Area Network (LAN) and Components
- Millimeter-Wave Doppler Radar
- IR CCD Imaging
- Phased-Array Antenna for Radar
- HEMT and FET Development
- Opto-Electronic Integrated Circuits
- Epitaxial Growth of HgCdTe by LPE, MOCVD, and MBE
- Fiber Optic Communications Components

JAE

- Laser Inertial Navigation Systems
- Laser Gyros
- Fiber Optic Gyros
- Accelerometers
- Color Flat Panel Displays
- Flight Control Sensors and Systems
- Electronic Connectors and Switches

Figure 3

Source: EO/MMW Team

SUMMARY OF FACILITIES AND TECHNOLOGIES
AUGUST 1986 JAPAN TRIP

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2.0 JAPANESE EO/MMW R&D ACTIVITIES - AUGUST 1986 VISIT

2.1 SONY

2.1.1 Company Background

The Technology Team had not previously visited Sony. The team saw the R&D facilities at the Osaki and Atsugi plants, and the Research Center in Yokohama. Sony, which was founded in 1946, primarily produces consumer oriented electronics. They reported net sales in 1985 of over $6 Billion at that year's exchange rate. (At current exchange rates, sales were $8 Billion.) About 74% of sales come from foreign markets and 25% from Japan. More than 76% of all sales are consumer products. Sony is seeking to rebalance their product lines to 50% consumer products and 50% industry oriented non-consumer products by 1990. The U.S. aerospace market is a likely target for much of this new direction.

2.1.2 Research Activities and Key Technologies

2.1.2.1 Osaki Plant

The Osaki plant is primarily an engineering center. They develop new products and pilot production lines. The focus of the visit to the Osaki facility was on video displays. They demonstrated a 19 inch, 1280 x 1024 pixel, color computer display monitor; a 20 x 20 inch, flat, 2048 x 2048 pixel, computer graphics display monitor; their new Indextron 5 inch monitor, which has a brightness of 1800 ft-Lamberts; and High Definition Television (HDTV) projection equipment. Sony officials told the team that they were also working on optical disk technology. They already have 5 inch, compact disk-read only memory (CD-ROM) and 12 inch, read-only video disk systems on the market. They also currently have 8 inch and 12 inch write once systems in production. The team was told that Sony is working hard on 12 inch erasable disks and they are probably 1 year away from production. They project a 5 inch read-write unit to cost from $400 to $600 and disks to cost $50 each.

2.1.2.2 Atsugi Plant

The Atsugi plant was established in 1960 and produced Sony's first transistor. With 6000 personnel, this plant was, until three years ago, Sony's captive supplier of semiconductor devices. It was reported that the plant currently produces from 120,000 to 150,000 CCD visible imager chips per month with better than 70% yield. But this production makes up only a part of the plant's output. Four other groups are engaged in R&D. They are the Semiconductors Group, Broadcast Devices Group, Media Information Product Systems (MIPS) which makes personal computers and automation systems, and the Mecatronics Group which makes printers and 3.5 inch disks. One half of Atsugi's 155,000 square meter facility is plant space. Eight hundred people are production technicians and there are 2500 professionals with engineering degrees. Some 2000 women with 2 year college degrees support the engineers.

The Information Research Center at Atsugi is engaged in research on the Global Positioning Satellite (GPS), image processing, artificial intelligence, magnetooptical erasable disks, perpendicular magnetic recording, digital signal processing, and communication systems (including 50 GHz systems). Three projects in particular were described for the team:

- Sony's Digital Data Recorder (DDR) (marketed as the VDR-2000) was designed for commercial and other broadcasting applications. The DDR has applications in physical measurement, image processing and very long baseline interferometry (VLBI). The system was used in September, 1985 in a joint Japan-China VLBI seismographic experiment.

- A video broadcast scrambler for digitally encoding and decoding CATV or DBS broadcasts.

- Radio Determination Satellite Service (RDSS) is being developed by Sony for use with Geostar Satellite Service. Geostar is a navigation (position) locator using a 1.6 GHz uplink, a 2.5 GHz downlink, and a 5-7 GHz uplink. The 1.6 GHz uplink transmitter uses dual matched

25 watt power transistors for 50 watts output at 47 dBm. A 72 MHz center filter enables spread spectrum demodulation. The system is designed for interrogation of a remote unit by a ground station, reply via two satellites, calculation of position by the ground station, and the reporting of position to the remote user. Global Positioning Satellite (GPS) work is directed at developing a prototype consumer use system. The target price for a GPS sensor, compact disk-read only memory (CD-ROM), and communication set is about the price of a car airconditioner.

- The GPS could be used in an interferometer application for seismic studies to predict earthquakes. A receiver for an institutional market (taxis, or trucking) could be used for highly accurate time transfer and position tracking.

2.1.2.3 The Research Center

The team also visited Sony's Research Center, one of four research centers Sony operates in Japan. The other centers are the Development Center, the Information Systems Research Center, and the Audio/Video Systems Center. At the Research Center, the team saw their metal organic chemical vapor deposition (MOCVD) research facility and YIG filter experiments. Sony is developing molecular beam epitaxy (MBE) for research and MOCVD for production.

Sony was the first company to produce AlGaAs/GaAs visible lasers by MOCVD for compact disc digital audio players and laser video disc players. In 1985, they started marketing MOCVD-produced 780 nm, 5 mW lasers and recently have added two high power (20-40 mW) lasers, operating at 780 nm and 820 nm for high-speed laser printer applications.

The Center developed two types of lasers:

- gain-guided lasers which incorporate a tapered stripe (TAPS) structure, and

- index-guided lasers which incorporate a self-aligned narrow stripe (SAN) structure

The mode of laser oscillation in the TAPS lasers is longitudinal multimode, while a single mode operation is possible in the SAN lasers.

In the TAPS structure, the wavefront in the tapered region remains the same as in the center region. The double-lobed far-field pattern of the beam inherent in the gain guide becomes single-lobed and the amount of astigmatism is small. Multimode operation is considered preferable for low noise applications as in optical discs. The devices cost about 1000 yen each.

The single mode, index-guided SAN laser is characterized by a stable far-field pattern and low astigmatism. Since light energy is confined efficiently within the cavity, a low lasing threshold and stable output at high power levels can be obtained with the SAN lasers.

Some 20,000 laser devices can be fabricated on a 5 cm diameter wafer using the MOCVD process while about 2000 lasers can be grown using liquid phase epitaxy on 1 cm^2 wafers.

The Center is actively developing YIG (Yttrium-Iron-Garnet) film tunable devices for GPS applications.

One-half of the staff have degrees in Physics and one-quarter have degrees in Chemistry. Current research is in semiconductor processes, optoelectronic junction lasers, and magnetic related, thin-film, and organic materials research. The Research Center's semiconductor research is in silicon-on-insulator and 3-dimensional semiconductors. They are developing MOCVD of GaAs for production uses. The Research Center began a project in 1970 to develop a charge coupled device (CCD). The project was intensified in 1972 and the Center spent the following five years in solving a defect problem. In 1977, the project was moved to the Atsugi plant for pilot line development.

In 1980, Atsugi delivered Sony's first commercial CCD product. The 10 year development was accomplished by transferring the R&D personnel to production and commercialization of the final product.

Sony researchers have also demonstrated their capability in advanced metal organic chemical vapor deposition (MOCVD) technology by fabricating low-noise high electron mobility transistors (HEMTs) with GaAlAs/GaAs heterostructures. Success in producing these devices is due to both the high quality of crystal growth and the abrupt heterointerfaces obtained by the MOCVD process.

Sony's HEMT consists of epitaxial layers of GaAs and AlGaAs. Hall mobilities are comparable to those obtained in layers grown by molecular beam epitaxy (MBE).

One device fabricated at the Research Center exhibited a minimum noise figure of 1.47 dB with 9 dB associated gain at 12 GHz. These results are comparable to microwave performances of GaAs metal semiconductor field effect transistors (MESFETs).

Sony has begun marketing a heterojunction field effect transistor (FET) called a HIFET (heterointerface field effect transistor) fabricated by the MOCVD technique. The transistor is Sony's term for a well-known high electron mobility transistor (HEMT). Sony has demonstrated a low noise HIFET/HEMT device with a 0.4 μm gate length and 0.8 dB noise figure. Following the lead of Gould, Inc., which announced the commercialization of HEMTs in November 1985, Sony has now become the second commercial supplier of HEMTs in the world.

Sony's HIFET products are available in two models: the 2SK-676 with a gate width of 200 μm and the 2SK-677 with a gate width of 300 μm. Both types have a gate length of 0.5 μm. At 12 GHz, for example, the devices have a noise figures of 1.2 dB and a typical gain of 11.0 dB at 300°K. Characteristics of the two models are listed below.

	2SK-676	2SK-677
Package	Ceramics	Ceramics
Gate Width	200 μm	300 μm
Gate Length	0.5 μm	0.5 μm
*nf (dB) Typ	1.2	1.2
Max	1.4	1.4
*gain(dB)Typ	11.0	11.0
Min	8.0	8.0

*f=12 GHz, Ta=300°K

The HIFET shows superior performance characteristics over the MESFET as indicated below.

	-40°C	-20°C	0°C	20°C
2SK-676(HIFET)nf(dB)	0.92	1.0	1.12	1.20
gain(dB)	12.5	12.1	11.8	11.6
2SK-575(MESFET)nf(dB)	1.28	1.31	1.36	1.40
gain(dB)	10.7	10.6	10.5	10.5

Test parameters:	12 GHz
2SK-676	V_{ds}=2 V, I_{ds}=10 mA
2SK-575	V_{ds}=3 V, I_{ds}=20 mA

2.2 OKI ELECTRIC INDUSTRY COMPANY, LTD.

2.2.1 Company Background

Oki Electric was founded in 1881 by Kibataro Oki, who built Japan's first telephone set. Initially involved in the manufacture of telephones, development and production is now directed at telecommunications systems, information processing systems, and electronic devices. In the U.S., Oki Electric is probably best known for their printers and display devices. In 1975, Oki entered a major joint-venture with AT&T to develop and produce mobile telephones for the U.S., Japanese, and international markets. A significant amount of resources were dedicated to this project. Other Oki products include switching systems for ISDN, transmission systems, fiber optics, PBX, banking systems, sonar systems, silicon integrated circuits, surface acoustic wave (SAW) devices, opto-electronic devices, image and signal processors, thermal image transfer color printers, gallium arsenide (GaAs) devices, high electron mobility transistors (HEMT), and 256K dynamic random access memory (DRAM) chips.

Net sales at Oki for 1985 were over 418 Billion yen ($1.67 Billion at the 1985 exchange rate of 250 yen to 1 U.S. dollar). This amount was an increase of 20.9% over the previous year. Overseas sales accounted for 31.1% of this figure. Five percent of the net sales, 20 Billion Yen, or $66 Million was devoted to R&D.

Oki has seven major production plants and a central research facility in Japan. The Tokyo Plant produces applied electronic systems. The Honjo Plant produces switching and transmission systems. The Takasaki Plant produces information processing systems, and the Hachioji Plant produces electronic components. The team visited the Central Research Laboratory. The previous EO/MMW Team did not visit Oki.

The Central Research Laboratory is composed of an Engineering Administration Division, the Research Laboratory, the Systems Laboratory, and the Ultra-Large-Scale Integration (ULSI) Laboratory. The Research Laboratory employs some 600 workers of whom 50% are Electrical Engineers, 10% hold PhDs, and the remainder have general physics or chemistry degrees. Figure 4 shows the twelve components of this Laboratory. Figure 5 shows the three departments of the Systems Laboratory. The team was not given any specific information on the ULSI Laboratory.

Research Laboratory

- Group Administration Department
- R&D Planning Office
- Dr. Isii's Research Section
- Information Processing R&D Department
- Information Terminal R&D Department
- ULSI Technology R&D Department
- Functional Devices R&D Department
- Optoelectronic Devices R&D Department
- Electronic Components R&D Department
- Materials for Electronic R&D Department
- Digital Communication R&D Department
- Digital Signal Processor R&D Department

Figure 4

RESEARCH LABORATORY ORGANIZATION

Source: OKI Electric

Systems Laboratory

- Knowledge Information Processing R&D Department
- Computer Systems R&D Department
- Office Systems R&D Department

Figure 5

ORGANIZATION

Source: OKI Electric

2.2.2 Research Activities and Key Technologies

2.2.2.1 GaAs and HEMT Technology

Oki is pursuing research and development in GaAs digital integrated circuits (ICs). They are working on several basic technologies for molecular beam epitaxy (MBE), metal organic chemical vapor deposition (MOCVD), tungsten-chemical vapor deposition (W-CVD), and non-alloyed contact materials. MBE is used for fabricating high electron mobility transistors (HEMTs) to achieve mobility levels of 10^5 at 77° K. They are working on reducing channel thickness from 400 to 200 angstroms. In MOCVD they are working with Vanadium doped high resistivity materials to achieve mobility levels of $1.6X10^5$ at 77° K.

MBE is also being used in a two step process to grow GaAs on Si. It involves high temperature surface cleaning followed by crystal growth. So far there is a problem of lattice mismatches at the interface.

The first successful fabrication of GaAs power field effect transistors (FETs) on GaAs epitaxially-grown layers on a silicon (Si) substrate by MOCVD and MBE was reported by researchers at Oki. The transconductance (g_m) of

these power FETs was typically 110 mS/mm which was comparable to that of FETs fabricated on a GaAs substrate. At 1 GHz, a power FET with 1 μm gate length and 5.4 mm gate width exhibited a linear gain of 10.2 dB, saturation output power of 2.3 W, and maximum power added efficiency of 38%. These rf performances are somewhat lower than those measured on FETs fabricated on GaAs substrates. However, because of the high thermal conductivity of the Si substrate compared with the GaAs substrate (about three times larger), these power FETs showed a low thermal resistance value of 5.3^{o} C/W, which was about half the value of FETs on GaAs substrates. For heat dissipation of GaAs power devices, the FET on GaAs/Si structure appears to have an advantage over the FET on GaAs.

A schematic cross-section of a GaAs power FET fabricated on the GaAs/Si substrate is shown in Figure 6. An n^+ Si(100) substrate was first heat-treated at 900° C for several minutes in a H_2 and AsH_3 flow for surface cleaning in a low pressure MOCVD system. Following the surface cleaning, the two-step growth procedure was used to grow GaAs layers. The procedure involves cooling of the substrate to below 450^{o} C and deposition of a thin, 200 Å GaAs first layer. Then the substrate temperature was brought to the conventional growth temperature of 700-750^{o} C and a vanadium doped semi-insulating GaAs layer of 1.5 μm was grown to isolate the active layer from the Si substrate. After the deposition of the V-doped GaAs layer, growth of an undoped buffer layer of 1.2 μm, a Si doped, n- active layer of 0.2 μm, and a 400 Å n^+- contact layer was carried out at 580^{o} C in a MBE system.

In the FET fabrication, the gate region was recessed by chemical etching and Ti/Pt/Au was evaporated to form the Schottky gate. The gates formed have a gate length of 1.0 μm and a gate width of 0.9 - 5.4 mm For device isolation, selective O^+ ion double implantation was employed. A dose of $2x10^{12}$ cm^{-2} at 30 keV and a dose of $3x10^{12}$ cm^{-2} at 80 keV were used for double implantation. Evaporated AuGe/Ni/Au was alloyed for ohmic contact formation.

Researchers at Oki believe that the rf performance of power FETs can be further improved by reduction of the parasitic capacitances between the Si substrates and bonding pads.

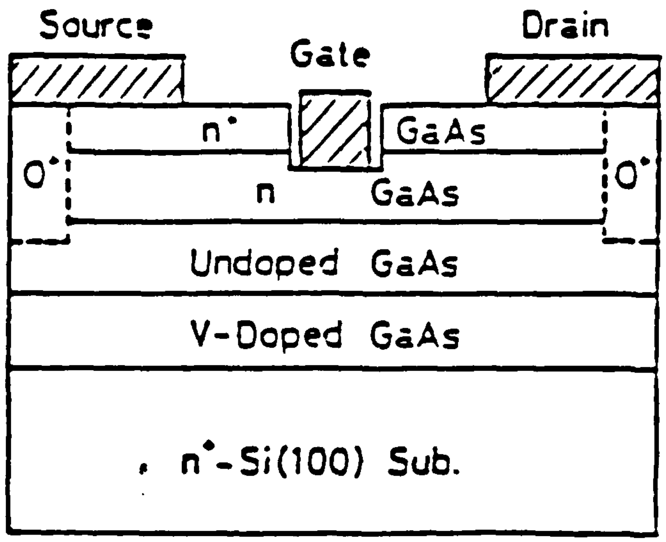


Figure 6

SCHEMATIC CROSS SECTION OF THE GaAs POWER FET FABRICATED ON A GaAs/Si WAFER

Source: Oki Electric

In digital integrated circuits (ICs) Oki is presently working in the 80-300 gates per chip range in GaAs. One project they are particularly interested in developing is a tungsten-aluminum (W-Al) Schottky gate for GaAs and SAW devices. Such a device would have a low resistivity and would be stable at high temperature annealing and operation. Oki is using a low molecular resist (LMR®) lift off process and deep ultraviolet (UV), (250 nm wavelength) lithography to achieve submicron features on integrated circuits. Oki has produced GaAs metal semiconductor field effect transistors (MESFETs) and field effect transistor (FET) array patterns on 2 inch wafers. They attribute their good uniformity to the high quality Indium (In) doped LEC subtrates. These devices use direct coupled FET logic (DCFL) and super buffered FET logic (SBFL) for high speed. The lab has developed a 1.5 GHz GaAs interfaced to CMOS (silicon) IC prescalar for use in cellular telephones. This device, in production for about 1 year now, has about 80 gates per chip and is made on a 3 inch wafer. Other GaAs devices include a 2:1 multiplexer/1:2 demultiplexer operating at 1-2 GHz frequency and 2 volts, 4:1 multiplexers, 1k gate arrays, and 4 kbit GaAs static random access memories (SRAM).

Oki is also developing analog GaAs ICs. They are making Ti Schottky gate low noise FET structures by direct ion implantation, air bridge, and low molecular resist (LMR®) processes. Other devices include radio frequency (RF) transmit/receive modules, monolithic microwave integrated circuit (MMIC) preamps with 2 FETs, 2 capacitors, and 8 resistors; dual FET mixers with 2 FETs, and 2 resistors; hybrid VCOs; and power amps.

An epitaxial process is being used to produce hetero-bipolar transistor (HBT) and HEMT structures. Oki is developing an inverted HEMT structure that has a smaller contact resistance (Gm about 10% greater than standard HEMT) and operates at 19.7 psec/gate at room temperature (K values same as standard HEMT at room temperature operation). This device is compatible with GaAs processes having a top layer of GaAs.

Oki's goals for the next five years in analog devices include working on microwave and millimeter wave monolithic integrated circuits. In digital devices, they are moving to medium scale integration (MSI) and large scale integration (LSI).

2.2.2.2 Optoelectronic Semiconductor Devices

Oki is actively engaged in research and development of optoelectronic devices such as laser diodes (LDs), photodiodes (PDs), and light emitting diodes (LEDs). They are currently using liquid phase epitaxy (LPE) and metal organic chemical vapor deposition (MOCVD) technology for crystal growth of InGaAsP/InP, InGaAs/InP, AlGaAs/GaAs, AlInGaP/GaAs. They are also just beginning research with gas source molecular beam epitaxy (MBE) for growing InGaAsP/Si to produce InGaAsP laser diodes on Si. Their target date for prototype production is June 1987. Oki's objective in using GaAs materials is for applications interconnecting optoelectric and digital devices directly. Table 1 describes applications for these growth techniques.

TABLE 1

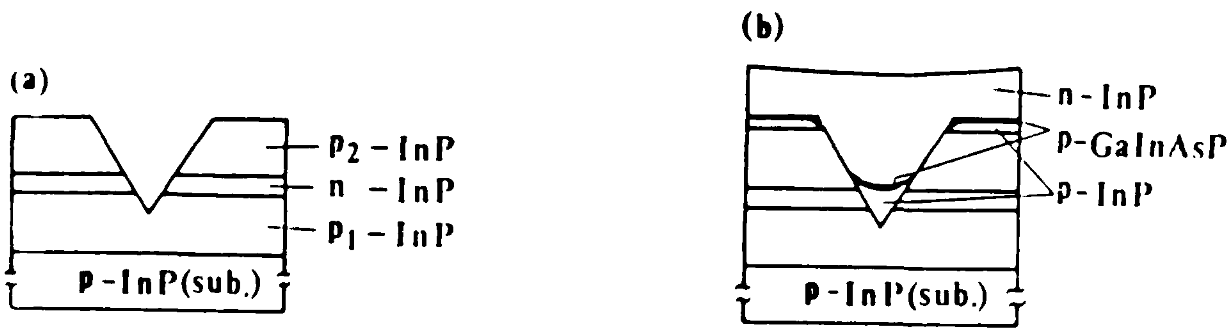
OKI's OPTO-ELECTRONIC DEVICES

Crystal Growth Technology	Materials	Application
LPE	InGaAsP/InP InGaAs/InP AlGaAs/GaAs	1.2, 1.3, 1.5 μm LD, 1.3 μm LED, BOD* PIN-PD, PIN-FET .83 μm LD, .7 μm LED Array
MOCVD	AlGaAs/GaAs, Si AlInGaP/GaAs InGaAsP/InP	.68 μm LD 1.3, 1.5 μm DFB-LD**
Gas Source MBE	InGaAsP/Si	InGaAsP LD on Si

* Bistable Optical Device
** Distributed Feed Back-Laser Diode

Source: OKI Electric

Oki has developed a variety of long wavelength high power lasers for fiber optic and atmospheric communication systems. The primary device under development is a V grooved inner stripe (VIPS) laser on P type InP substrate (see Figure 7).



(a) Lower Layers (b) Upper Layers

Figure 7

VIPS STRUCTURE

Source: OKI Electric

In order to achieve high power output, Oki's researchers have developed a VIPS with a high breakdown voltage of a P on N InP junction for a 70% efficiency, low threshold current of 15mA and a high operating temperature of 140° C. They have optimized the cavity length between 300 and 700 m increasing output power 50% and optimized the asymmetric facet coatings for a front reflectivity of 2% and a rear reflectivity of 90%, to increase the output power 100%. The design parameters and operating characteristics are given below in Table 2 and 3.

TABLE 2

HIGH POWER VIPS LASER DESIGN PARAMETERS

Conducting Type of InP Substrate	P-Type
Waveguide Type	Index Guided
Shape of Active Layer	Crescent Shape
Active Layer Thickness	0.1 μm
Active Layer Width	1.5 μm
Cavity Length	700 μm
Reflectivity of Front Facet	2 %
Reflectivity of Rear Facet	90 %
Crystal Growth	LPE

Source: OKI Electric

TABLE 3

HIGH POWER VIPS LASER CHARACTERISTICS

Lasing Wavelength (μm)	Maximum Output Power P_M(mW)	Threshold Current I_{th}(mA)	Differential Quantum Efficiency η_0(%)	Maximum Operating Temperature T_M (^oC)	Cutoff Frequency f_c (GHz)
1.20	200	15	70	140	2
1.31	200	15	70	140	2
1.47	100	20	60	120	2
1.55	100	20	60	120	2

Source: OKI Electric

Other long wavelength semiconductor devices include superluminescent diodes (SLDs) operating at 1.3 μm wavelengths and 3mW; edge-emitting light emitting diodes (LEDs) at 1.3 μm wavelenghts, 0.5mW output power, and 200 MHz center frequencies; 1.3 μm bistable lasers; and InGaAs PIN (P-intrinsic-N) photodiodes (PDs) with 1.2-1.55 μm spectral response, 70% efficiency, and 2 GHz center frequency.

Oki is also working on single mode laser modules. They use a confocal lens combination to couple 9 μm core diameter single mode fibers. Typical output powers for different light sources are listed in Table 4.

TABLE 4
LIGHT SOURCE OUTPUT POWERS

LIGHT SOURCE	OUTPUT POWER
200 mW & 1.3 m LD	100 mW
200 mW & 1.2 m LD	100 mW
100 mW & 1.5 m LD	50 mW
3 mW & 1.3 m SLD	1 mW
0.5 mW & 1.3 m EE-LED	50 μW

Source: OKI Electric

Oki's high power AlGaAs visible lasers (see Figure 8) use an inner stripe structure for current confinement, a V grooved channeled substrate, and a large optical cavity waveguide structure.

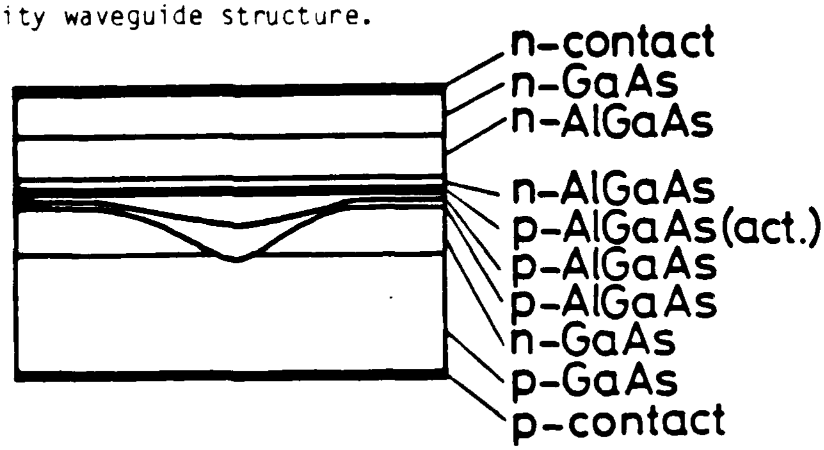


Figure 8

HIGH POWER AlGaAs VISIBLE LASER STRUCTURE

Source: OKI Electric

The active layer thickness is 750 angstroms, cavity length is 250 μm, front facet reflectivity is 10%, and rear facet reflectivity is 90%. Typical characteristics of Oki's visible lasers are given in Table 5.

TABLE 5
VISIBLE LASER CHARACTERISTICS

CHARACTERISTIC	VALUE
Lasing Wavelength	830 nm
Threshold Current	80 mA
Maximum Output Power	80 mW
Differential Quantum Efficiency	47 %
Characteristic Temperature	200 K
Far Field Pattern	12°-25°
Supression Ratio	-30 dB

Source: OKI Electric

Other AlGaAs devices under development include 900 nm, 2.1 W high power pulsed lasers, AlGaAs light emitting diode (LED) on Si at 700 nm, AlGaAs 840 nm LED for fiber optics with output power of 2 mW and 100 MHz center frequency, and an AlGaAs PNPN diode.

Over the next five years in optoelectronic devices, Oki is going to pursue R&D in monolithically integrated distributed feedback (DFB) lasers on Si LSI wafers, surface emitting laser matrixes, microlasers, high power visible lasers, avalanche photo diodes (APDs), receiver modules monolithically integrated on Si LSI wafers, and LED arrays monolithically integrated on Si with Si LSI driver circuits. Oki expects to use metal organic chemical vapor deposition (MOCVD), gas source MBE, reactive ion etching, and fine pattern wafer processing for multi-layered compound semiconductor structure formation.

2.2.2.3 Advanced High Speed Data Vehicular Radio Communication & Network Management

Oki has been engaged in a 10 year cooperative program with Bell Laboratories in the development of cellular mobile telephone systems. Oki is currently

seeking to expand the platforms for mobile phones (and their market) to aircraft, trains, and boats. They are also working on increasing the system capabilities to include facsimile and data terminals as well as telephone service. Figures 9 & 10 illustrate Oki's concept for an Integrated Mobile Communication System and a Battle Communication System. In test sets, Oki engineers have achieved uncontrolled error rates of 2.5 x 10^{-2} and error rates with error control of 10^{-6} or better for an average transmission quality with error control of about 55%.

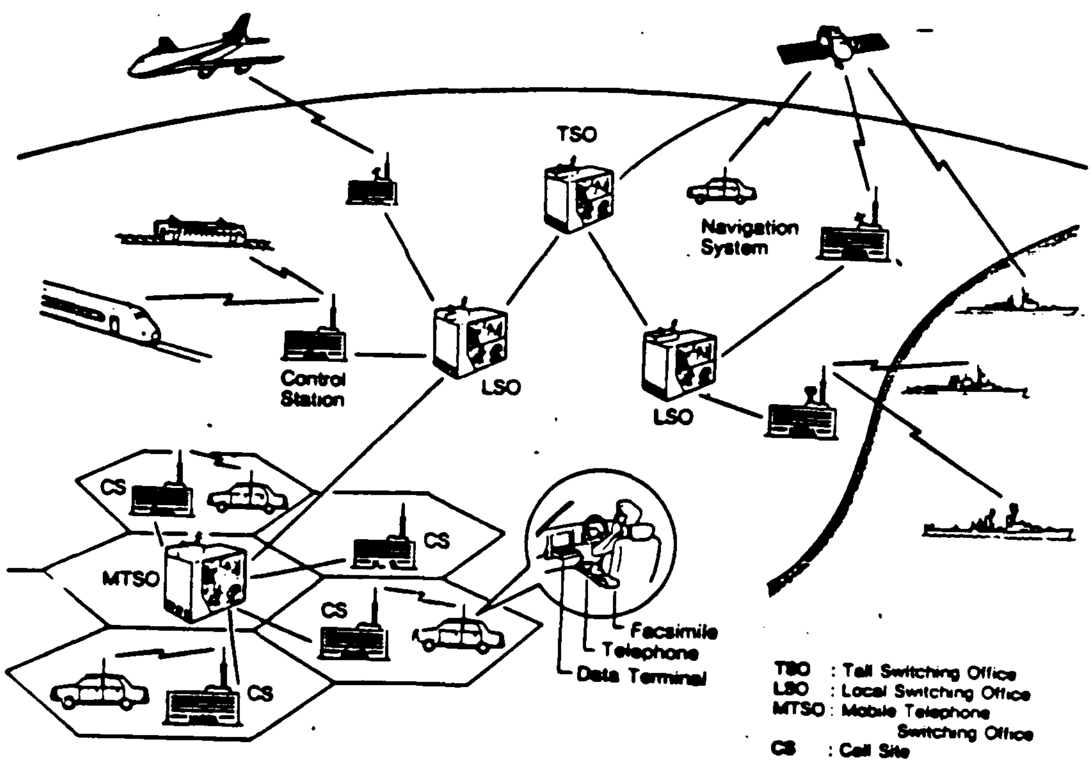


Figure 9

INTEGRATED MOBILE COMMUNICATIONS SYSTEM

Source: OKI Electric

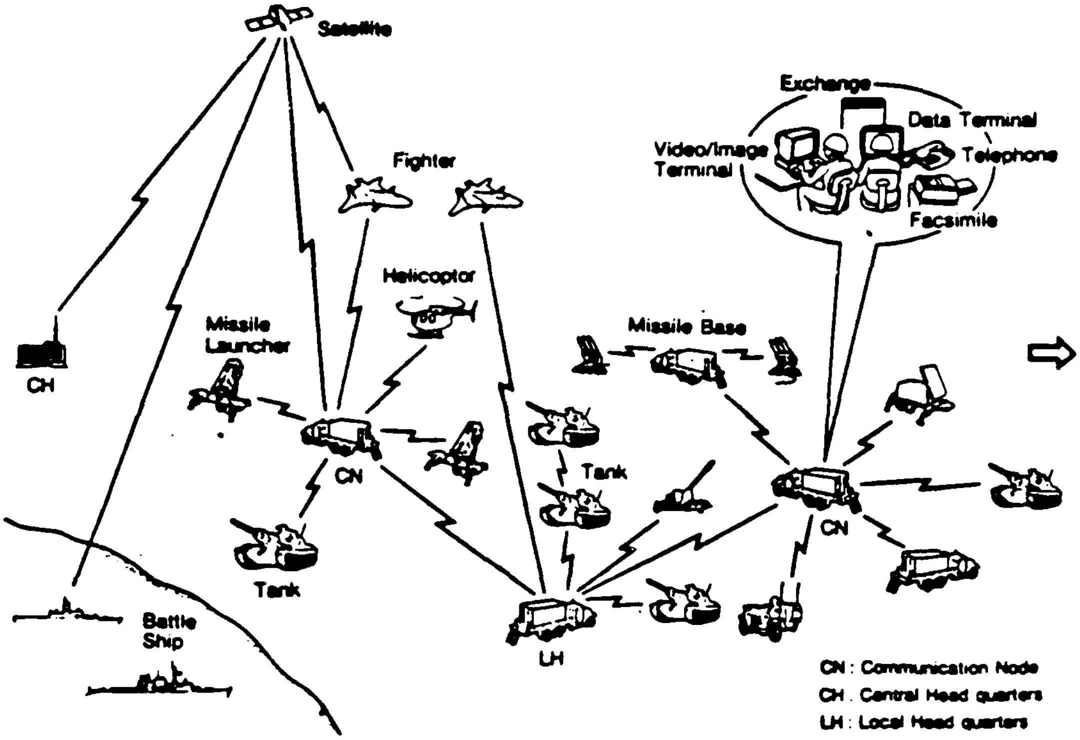


Figure 10

BATTLE COMMUNICATIONS SYSTEM

Source: OKI Electric

2.2.2.4 Optical Fiber Transmission Systems

Oki is pursuing research and development on 1.2 and 1.3 μm wavelength, single mode optical fibers for wave division multiplexing (WDM) applications. This work is aimed at developing practical devices with high performance (low loss 0.7-1.0 dB, low, 45 dB crosstalk , 30 dB return loss) and stability (low loss variation of 0.25 dB), low cost, compact size, easy installation, and multipurpose applicability. These single mode fibers have a core diameter of 9 μm and a clad diameter of 125 μm. Their pass-band wavelength is 1200 $\pm$ 25 nm and 1300 $\pm$ 25 nm with a pass-band loss of <1 dB, stop-band attenuation >45 dB, and return loss >30 dB.

A number of optical data transmission modules have already been developed using light emitting diode (LED) and laser diode (LD) sources and P-intrinsic -n photodiode (PIN-PD) or avalanche photodiode (APD) detectors and both multi- and single mode fibers. These various modules operate from 1.5 Mb/s

up to 140 Mb/s. Some incorporate integrated transmit and receive circuits while other modules separate these components. Several modules also use wave division multiplexing (WDM). These modules are used in inter-office networks and offer high reliability, reshaping/retiming/regeneration (3R) circuits, compactness, low power consumption and utilize LSI circuits. Figure 11 gives typical specifications for transmitter and receiver modules.

ITEM	OPTICAL RECEIVER MODULE SPECIFICATIONS	OPTICAL TRANSMITTER MODULE SPECIFICATIONS
Information bit rate	44.736 Mb/s	44.736 Mb/s
Line code	CMI/5B6B/8B1C	CMI/5B6B/8B1C
Detector	Ge-APD	InGaAsP-LD
Minimum optical power	-40 dBm	2 dBm (peak)
Timing circuit	SAW filter	2 fiber core op. 1.31 μm/ 1 fiber core op (1.2 μm, 1.31 μm)
Optical interface	50/125 μm GI fiber FC pigtail	50/125 μm GI fiber FC pigtail
Electric interface	ECL	ECL
Power	-5.2V $\pm$ 5%	+5V $\pm$5%/-5.2V $\pm$5%
Dimensions (mm)	100 x 100 x 24	100 x 100 x 24

Figure 11

OPTICAL MODULE PARAMETERS

Source: OKI Electric

Oki is also involved in development and production of long distance optical fiber transmission equipment. Their ODL-500 and ODL-600 systems use InGaAsP LD sources and Ge APD detectors, and single mode 10 μm core diameter optical diameter optical fiber. Operating at 32 Mbps or 97 Mbps information bit rates, these systems have allowable transmission losses of about 20 dB and repeater spacing of about 35 km.

2.2.2.5 Digital Signal Processing Technology

Oki started developing digital signal processors (DSP) as specialized microprocessors in 1980. In 1985, their digital signal processor work entered second generation performance. Oki's current DSPs operate above 10 MHz and come in fixed- or floating-point formats. The MSM6992 features 20 Mflop (10 MHz) or 16 Mflop (8 MHz) operation with large capacity on-chip data random access memory (RAM) of 256 words (128 W x 2), large capacity on-chip program read only memory (ROM) of 1 Kword, and program memory expansion and data memory expansion of up to 64 Kwords each. This low power, micron feature size, CMOS device, uses 500 or 400 milliwatts depending on the speed set.

2.2.2.6 Artificial Intelligence (AI) and Fifth Generation Computers

Oki is one of eight Japanese companies actively engaged in Japan's 5th Generation Computer Project. The other companies are Mitsubishi, Matsushita, Sharp, Hitachi, NEC, Fujitsu, and Toshiba. The Institute for New Generation Computer Technology (ICOT), located in the Mitakokusai Building in Tokyo, coordinates the research for MITI. Between 1982 and 1991, topics to be researched by Oki as part of the 5th generation computer project include: parallel inference machines (PIM), a distributed knowledge base machine referred to as PHI, personal sequential inference machine (PSI), programming and operating systems for the PSI machines (SIMPOS), an advanced communication network (ICOT-NET), an LSI-CAD expert system, an electronic switching system (ESS), a software design expert system, natural language summarization software, and electronic dictionaries. As part of the related Super Computer Project, work is proceeding on a parallel 3D graphic processor and 3D graphic software. In artificial intelligence (AI), Oki is working on an expert system development tool called Rule Runner, an AI programming language compiler called Prolog/SL, machine translation between Japanese and English, and a LISP machine called ELIS.

Oki's AI and advanced computer development work is done in their Systems Laboratory. The Knowledge Information Processing Department is working on

AI, computer vision, and signal processing. The Computer System Department is working on PSI architecture, SIMPOS software, PIM and PIMOS parallel processing, and a distributed knowledge base system for the PSI system. The Office System Department is working on a LISP AI workstation, operating system, and support languages, and natural language/machine translation systems.

2.2.2.7 Sonar Signal Processing (SP) and Advanced Robotics Project

Oki is also engaged in another long term development program. This program, the Advanced Robot Project, was begun in 1983 and will run through 1990. The goal of the project is to develop an advanced robot suitable for underwater applications utilizing sophisticated underwater acoustic imaging. Such a robot system could be used in oil exploration and exploitation. Research is proceeding on the acoustic imaging system for robot vision as well as an underwater acoustic telecommunication system for image transmission.

2.3 MITSUBISHI ELECTRIC CORPORATION (MELCO)

2.3.1 Company Background

Mitsubishi Electric was established in 1921 and today is one of Japan's leading manufacturers of electrical and electronic equipment. Net sales for 1985 were over $8.1 Billion (converted using 250 yen to 1 U.S. dollar). MELCO has close to 69,000 employees including consolidated subsidiaries. Primary products include communication and space development, information-processing systems, electronic devices, energy, transportation, building equipment and systems, industrial equipment, and consumer products. In Japan, apart from their corporate headquarters, MELCO has 34 Works and Factories, and 9 Laboratories.

The Technology Team revisited MELCO's Kamakura Works. This facility began operations in 1962 primarily producing communications equipment. In the current 130,000 m^2 of buildings, MELCO researchers also develop space systems and industrial electronics.

2.3.2 Research Activities And Key Technologies

At the Kamakura Works, the team was shown research on an IR charge sweep device, millimeter wave technology, microwave GaAs circuits, and a missile simulator. During the Plant tour, they saw a transonic wind tunnel facility, a 3-axis flight table (part of the missile guidance and control system simulator), a one arm robot, and a 1m x 1m green, yellow, red, and orange LED display.

2.3.2.1 Infra-Red Charge Coupled Device/Charge Sweep Device (IR CCD/CSD) Research and Development

MELCO has developed an IR charge coupled device (CCD)/charge sweep device (CSD) using PtSi Schottky Barrier materials. This design is effective for decreasing blooming.

A glass Dewar holds the charge sweep device (CSD). The Dewar has a germanium (Ge) window. Two types of coolers have been developed. One is a Joule-Thomson open type using nitrogen gas. The other cooler is a Stirling cycle closed type using a compressor with a cold finger. Performance of a prototype camera was reported to be 0.13° C NETD for a 4° x 3° field of view.

2.3.2.2 Millimeter Wave Technology

As on the first team visit to MELCO, the team was shown a 94 GHz millimeter wave seeker head. Developed before 1984, the device uses Si IMPATTs. The double side band (DSB) front end mixer uses GaAs beam lead Schottky Barrier diodes. While this device has not appreciably changed since the first time the team saw it, MELCO officials did say that they intend to reduce the size of the seeker head.

2.3.2.3 Microwave GaAs Circuits

MELCO has developed a number of GaAs monolithic ICs for microwave applications. Circuits described to the team included:

- Four-stage field-effect-transistor (FET) amplifier consisting of 5 separate chips.
- Two-stage, X-band, low noise amplifier (LNA) operating at 17 dB gain and 3.5 dB noise figure.
- Five-bit, X-band, FET phase shifters for 11.25°, 22.5°, 45°, and 90° that handle 10 mW power.
- FET transmit/receive switches.
- K_a-band multiplier for satellite applications doubles 13 GHz input to 26 GHz output with 3dB output power loss. Device chip size is 3 x 2 mm.
- Divide by 2 frequency divider operates by a non-linear method. 14 GHz input divided to 7 GHz output with an 8 dB conversion loss.

2.4 MATSUSHITA

2.4.1 Company Background

Matsushita Electric was founded in 1918. Under the brand names of "National", "Panasonic", "Technics", "Quasar", and "JVC", Matsushita's products are sold in more than 130 countries around the world. Consolidated sales for 1985 exceeded $24.9 Billion. Overseas sales accounted for 50% of this figure. Matsushita is a commercial/consumer product oriented company. They are divided into six commercial product groups: video equipment, audio equipment, home appliances, communication and industrial equipment, energy

and kitchen-related products, and electronic components. In 1985, $9 Billion came from sales of video equipment and $4 Billion from communications and industrial equipment. Audio equipment, home appliances, energy and kitchen-related products made up another $7 Billion. Almost $3 Billion came from the sale of electronic components. $1.2 Billion, almost 5% of sales, was invested in R&D last year. Work centered on rapidly advancing electronics and microelectronics technologies. Matshushita is aiming to double industrial product sales over the next three years and move away from the existing reliance on consumer products. They will do this by heavily investing resources in office automation (OA) and new audiovisual (AV) equipment, factory automation (FA), and semiconductors.

Matsushita Electric has over 130,000 employees and its technical headquarters is divided into the Corporate Engineering Division, the Corporate Product Development Division, and the Semiconductor Research Center. The team revisited the Central Research Laboratories in Osaka.

2.4.2 Research Activities And Key Technologies

Matsushita presented technical information to the team on the following topics.

2.4.2.1 Pyroelectric Materials and Sensors

Matsushita is using pyroelectric thin-films for infra-red (IR) detectors. They are using $PbLa(TiO_3)$ materials for high detectivity, and high resolution. The material is prepared by radio-frequency (RF) magnetron sputtering. The substrate is a cleaned and polished single crystal of MgO (with 1-0-0 orientation). Their goal is to produce $Pb^{0.9}La^{0.1}Ti^{0.978}O_3$ powder (called PL10).

2.4.2.2 High Q Dielectric Materials

Matsushita has developed two types of low loss, temperature stable, high Q dielectric ceramic material for microwave applications. These materials

have applications as dielectric resonators for highly stabilized oscillators, low loss narrow band filters, substrates for microwave integrated circuits, microwave chip capacitors, and microwave discriminators.

2.4.2.3 SAW Dispersive Filters

Matsushita researchers are working on surface acoustic wave (SAW) dispersive filters for high frequency applications at hard to control frequencies.

2.4.2.4 Monolithic Microwave ICs

Matsushita's monolithic microwave IC (MMIC) work in GaAs is directed at ultra-high and super-high frequencies (UHF and SHF), and developing new processes and devices. Devices described included a negative feedback, wideband amplifier, 3-stage low noise amplifier (LNA), a UHF mixer, a three-stage SHF amplifier, and a SHF mixer using dual gate FETs with the intermediate frequency (I_f) amplifier on the same chip.

A new self-aligned FET is under development. It is a metal refractory-silicide, double layer gate. The primary application of all these devices is in Direct Broadcast Satellite (DBS) receivers.

2.4.2.5 Direct Broadcast Satellite (DBS) Receivers

Matsushita's low noise converter for DBS receivers features an arsenide-sintered, alumina substrate with a thick film microwave integrated circuit This circuit features through-hole grounding of FET sources, highly stable local oscillators, high reliability, and small size. Device specifications were reported as:

• Receive Band	11.7 - 12.2 GHz
• I_f out	0.95 - 1.45 GHz
• Noise Figure	2.5 dB maximum
• Input VSWR	2.0 maximum
• Conversion Gain	50 $\pm$ 2 dB

- Image Rejection Ratio 50 dB
- Local Frequency Stability $\pm$ 1.0 MHz (-40° to +60° C)
- Dissipation Power 2.7 W

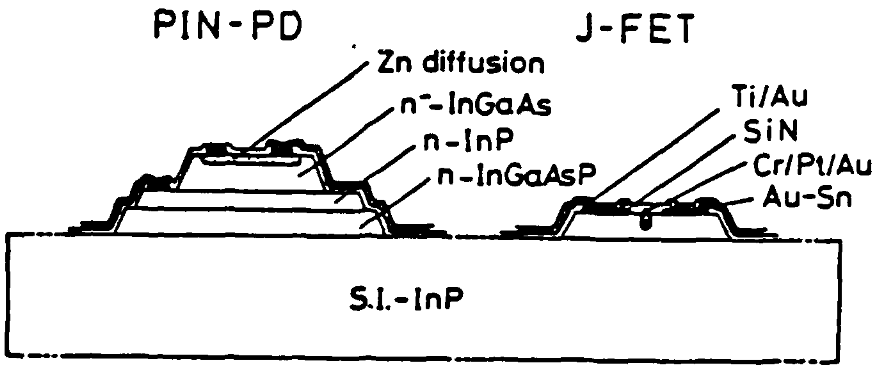
2.4.2.6 Optical Devices

Researchers at Matsushita discussed several optoelectronic integrated circuits (OEICs) with the team. The first device was a fully monolithic OEIC photoreceiver. It consists of a PIN (P-intrinsic-N) photodiode (PD) and a transimpedance preamplifier on the same chip. The transimpedance amplifier converts optical signals to electrical voltages. Operating from a single 5 volt power supply the device is emitter coupled logic (ECL) compatible so it can be directly connected to standard digital devices. The preamplifier consists of four JFETs, four level shift diodes and a feedback resistor. The photoreceiver was fabricated using liquid phase epitaxy (LPE). The first and second layers were used for the photodiode. Zn was diffused into the first layer to form the p-n junction. The third layer was for the other devices. (see Figure 12)

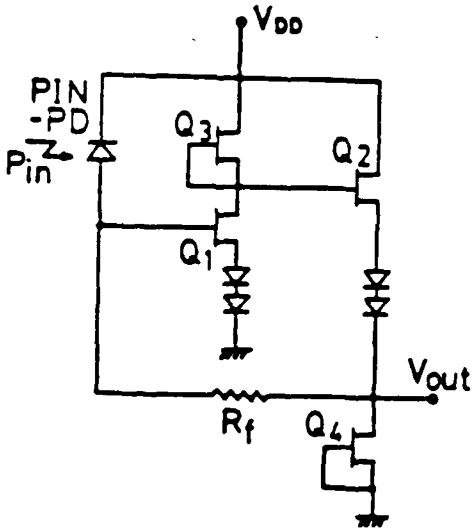
An OEIC laser diode (LD) and driver was described as the planar monolithic integration of an InGaAsP/InP laser diode with a hetero-bipolar-transistor (HBT) driving circuit. The device operates at 5 volts and has been tested up to 1.6 GHz. (see Figure 13)

An integrated passive cavity (IPC) laser made of InGaAsP/InP reportedly offers small size, long term optical and mechanical stability, single frequency oscillation, and narrow spectral linewidth.

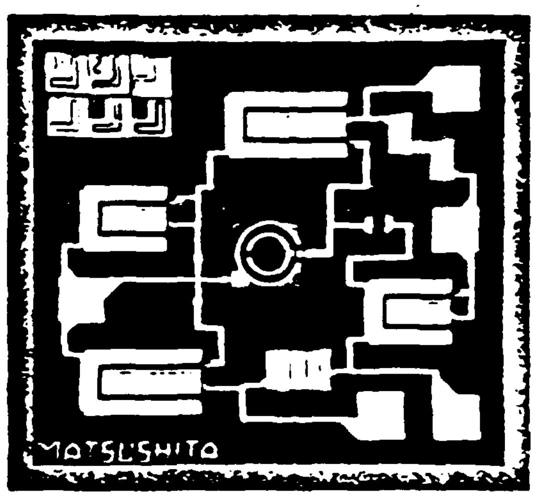
The final OEIC device discussed was a thin film integrated optic second harmonic generation (SHG) guided wave doubler. Constructed on a $LiNbO_3$ substrate, the device uses a proton exchange waveguide to achieve a high resistance to optical damage and a high refractive index change.



a) Chip Structure



b) Equivalent Circuit



c) Photomicrograph of Circuit

Figure 12

PIN PD AND TRANSIMPEDANCE AMPLIFIER OEIC

Source: Matsushita

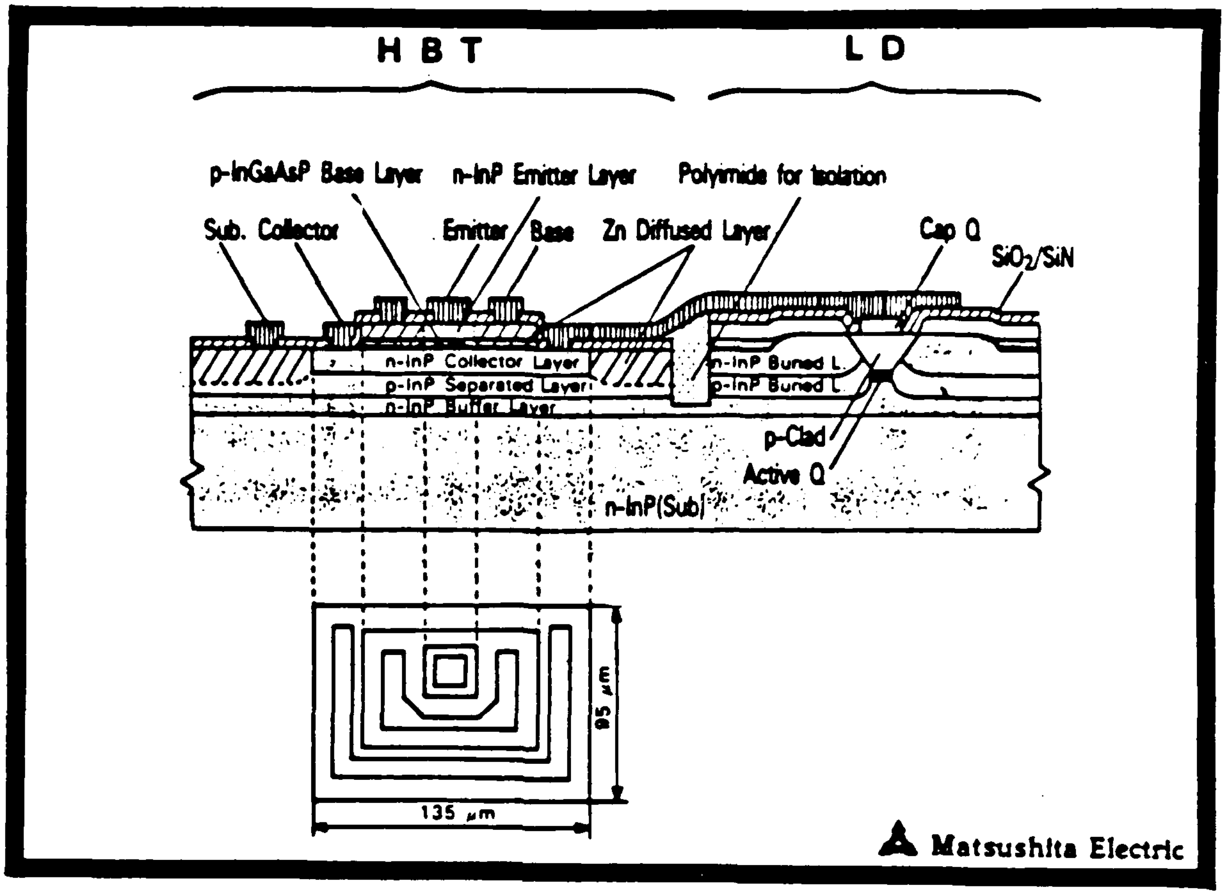


Figure 13

LD/DRIVER OEIC

Source: Matsushita

2.4.2.7 Optical Disks

Matsushita is investigating phase change media for optical disks. Phase change media offers high quality, high sensitivity, simple disk construction, and probably most important of all, reversability. They stated that they are not far away from commercialization.

Matsushita is already producing write once disks for their own very sophisticated video recorders (Panasonic TQ-2300F) and office automation document storage systems. Marketed by Panasonic under the name Panafile-10 the office automation system can store 1.45 Gigabits per side of a 20 cm disk.

2.4.2.8 Fiber Optic Communications and Data Links

During the first visit of the EO/MMW Team to Matsushita it was reported that Matsushita's commercial optical fiber communication systems included a 714 Mbps digital pulse code modulation (PCM) transmission system for high definition TV and an analog wideband transmission system for 7 channel very high frequency (VHF) frequency division multiplexing (FDM) TV signals. Two years later, the digital system is now capable of 8-bit encoded, 800 Mbps for 8 channel PCM TV signals. Span length is 25 km and the system uses a 1.3 μm laser diode (LD) source and avalanche photodiode (APD) detector. They have also developed 100 Mbps and 32 Mbps digital systems for local area networks. The analog system has been expanded to include ultra high frequency (UHF), direct broadcast satellite-intermediate frequency (DBS-IF) (1.3 GHz) multichannel FDM TV signals. Their fiber optic multichannel TV transmission system uses monomode fiber, a 1.3 μm LD source, and an APD detector. There are models for VHF, UHF, and DBS-IF (1.0-1.5 GHz) bands.

2.5 NEC CORPORATION

2.5.1 Company Background

NEC was founded in 1899 as Japan's first joint-venture. NEC was founded as an importer and manufacturer of telephone sets and switching equipment. The joint-venture was with Western Electric of Illinois (now part of AT&T Technologies).

NEC is now one of the largest electronics companies in Japan. They currently have over 95,000 employees in 50 domestic plants and 24 plants in 13 countries around the world. Last year net sales were over 2,334 Billion yen or almost $9 Billion (at 251 yen to 1 U.S. dollar). NEC's major product areas are communications (32% of sales), computers and industrial electronic systems (35% of sales), electron devices (19% of sales), and home electronics (8% of sales). Current R&D and marketing efforts are aimed at computers and communications (C&C). NEC markets over 15,000 products in more than 140 countries. Overseas sales represented 34% of all sales in 1985.

NEC has 9 operating groups. These groups cover the following areas:

- Switching Group -- electronic telephone switching systems for central office and PBX uses, digital switching systems, telephone sets, key telephone systems, video telephone equipment, and electromechanical devices.

- Transmission and Terminals Group -- teleconference systems, facsimile equipment, CATV systems, carrier transmission equipment, power-line carrier equipment, submarine cable repeaters, fiber optic communications systems, optical connectors.

- Radio Group -- microwave communications systems, over-the-horizon communications equipment, satellite communications systems, millimeter wave communications equipment, laser communications equipment, mobile and portable radio equipment, pagers, cordless telephone sets, TV and radio broadcast equipment, VTR and studio equipment, DBS receivers, aircraft and space electronic equipment, satellites, rocket guidance and control equipment, radio navigation and radar equipment, defense electronic systems, underwater ultrasonic application equipment.

- Information Processing Group -- supercomputers, general-purpose ACOS series computers, minicomputers, personal computers, data communications equipment and software, peripheral and terminal equipment, magnetic memory equipment, optical disk players, OA systems, word processors, LAN systems, speech recognizers, robots, CAD/CAM and CAE systems.

- Electron Device Group -- ICs, LSI and VLSI devices, microprocessors, transistors, diodes, GaAs FETs, hybrid ICs, gate arrays, LCDs, CCDs, electron tubes, microwave tubes, color picture and display tubes, plasma display panels, lasers, LED, APD, photodiodes, laser application devices, circuit components, rectifiers, and bubble memories.

- Home Electronics Group -- color and black and white TV receivers, VCRs, portable video cameras, TV projectors, radio receivers, transceivers, tape recorders, hi-fi audio systems, compact disk digital audio players, lighting products, refrigerators, microwave ovens, kitchen appliances, air conditioners.

- Special Projects Group -- Electrical connectors, aircraft electronics, measuring and testing systems, vacuum equipment.

- Research and Development Group -- Made up of 10 groups of laboratories and about 1200 people performing basic and applied research.

- Production Engineering Development Group -- Responsible for upgrading production technologies.

NEC returns 10% of sales ($1.5 Billion) to research and development. The R&D Group gets $150 Million of this funding. The remaining $1.35 Billion goes to R&D in the various product divisions. Less than 5% ($75 Million) of all R&D funding comes from outside sources. Only $5-10 Million comes from JDA contracts.

The R&D Group, employing about 1200 people, is engaged in "research and development for the day after tomorrow". The group is chartered to develop technologies in the areas of materials, devices, equipment, systems, and software. These areas form the basis for NEC's integration of computers and communications (C&C). There are ten groups of laboratories and centers in the R&D Group. They are listed in Figure 14.

During their revisit of NEC's facilities, the team was briefed by members of the R&D Group, the Electron Device Group, and the Radio Group.

- Fundamental Research Lab (materials research)
- Microelectronics Research Lab
- Opto-electronics Lab
- C&C Systems Research Lab
- C&C Information Technology Research Lab
- Software Product Engineering Lab
- Microcomputer Software Development Lab
- Resources and Environment Protection Research Lab
- Material Development Center
- Scientific Computer Center

Source: NEC

Figure 14

LABORATORIES OF NEC's R&D GROUP

2.5.2 Research Activities And Key Technologies

2.5.2.1 Charge Coupled Devices (CCDs)

NEC is working on visible CCDs that have high transfer functions which result in high contrast.

An infra-red charge coupled device (IRCCD) developed at NEC is made from PtSi. The device is cooled by liquid nitrogen.

NEC is working on electronically shuttering CCDs. This technique is an effective way to eliminate blooming, while providing high sensitivity and dynamic range. They currently have six commercial products and three experimental devices under development. NEC markets a full line of CCD cameras, some with frame interline transfer (FIT) to reduce smear and

variable shutter speeds from 60 to 2000 frames per second. These cameras are used for commercial broadcast slow-motion and instant replay of sports events.

2.5.2.2 Compound Semiconductor Devices

Research and development of compound semiconductor devices at NEC includes work on diodes, GaAs field effect transistors (FETs), and GaAs integrated circuits (ICs). Researchers have produced Schottky barrier, Si PIN, IMPATT, and Gunn diodes. GaAs FET work has been related to developing various metal semiconductor field effect transistors (MESFETs) (both low noise and power FETs) and high electron mobility transistors (HEMTs). Selective metal organic chemical vapor deposition (MOCVD) is used to fabricate the MESFETS. HEMTs are produced on AlGaAs/GaAs epitaxial wafers by molecular beam epitaxy (MBE).

To produce more advanced ICs, NEC researchers are working on GaAs growth techniques. Using thermal stress analysis to reduce slip bands and Indium (In) concentrations, NEC is producing LEC-grown dislocation-free (DF) GaAs substrates. This work compares favorably with state-of-the-art developments in the U.S.

GaAs IC development at NEC includes both monolithic microwave integrated circuits (MMICs) and digital ICs. MMIC devices include:

- Wide-band and Ultra-wide-band amplifiers with 2-3 dB gain over 2-26 GHz operating at 5 volts and 140 mA.

- 12 GHz radio frequency (RF) converter for direct broadcast satellite (DBS) applications with integrated preamp, mixer, and postamp and separate local oscillator (LO). With a LO frequency of 10.8 GHz at 10 dBm, the frequency converter has a gain of 40 to 30 dB and noise figure of 2 to 4 dB over 11.0 to 12.0 GHz.

- 28 GHz 1-stage medium power amp operating at 24 dBm and 3dB gain with 8% power added efficiency.

- 30 GHz, 2-stage, low noise amplifier (LNA) with 5 dB gain.

- 13 GHz double balanced mixer.

- Dual modulus (128/129) low power prescaler for mobile telephones operating at 1 GHz on a 5 volt supply has an input sensitivity of -20 dB.

- 6 GHz static divide by 4 prescaler will be commercially available by late 1986.

- R&D continues on a dynamic divide by 32 prescaler.

- 1 GHz, baseband and 2 x 4 switch matrices have good isolation characteristics.

NEC's GaAs digital ICs are fully emitter coupled logic (ECL) compatible. Most are of fairly low complexity. Small scale integration (SSI) devices are currently commercially available. Medium scale integration (MSI) circuits are expected to be commercially available by the end of 1986.

Research and development is continuing on large scale integration (LSI) devices. So far researchers have developed a 3k gate array that operates at 1 GHz and a 4k static random access memory (SRAM) with 3.6 nsec access time, .8 μm feature size, 1.3 μm gate lengths, and 1.8 W power dissiption.

AlGaAs hetero-MIS depletion mode InP FETs are also being developed. These devices have demonstrated high power gain, small hysteresis, no drift, and an insensitivity to light illumination.

NEC has also developed an AlGaAs/GaAs hetero-junction bipolar transistor (HBT). Simulations indicate a possible cutoff frequency of 45 GHz and propagation delay of 25 psec.

2.5.2.3 Optical Fiber Components

NEC has an extensive line of commercially available optical fiber components. They have a variety of optical couplers which split or combine two or more optical signals. Optical couplers are used in a wide range of optical communications systems and measurement instruments. Using the NEC designed and patented SELFOC lens, these optical couplers feature low loss, compact and lightweight size, and are rugged and resistant to thermal or mechanical distortion. Couplers are made in a wide range of splitting ratios and wavelengths by altering the dielectric multi-layer film used as a half mirror. One-to-one image conversion by a parallel beam is used for coupling between optical fibers giving the coupler a low mode dependency. Low mode dependency is a requirement for analog and digital communications, as well as measurement systems which use a laser diode as a light source. NEC produces 2-port, 3-port, and 4-port couplers. A modified 3-port coupler design is used with a PIN photodiode as a line monitor.

Other devices include optical isolators for 0.85 μm and 1.3/1.5 μm wavelengths; a very stable 5 volt, 120 mA, 18 millisecond optical bypass switch; a rugged optical connector for a 1 mm diameter beam, with SELFOC lens for a transportable system; and several types of optical wavelength division multiplexer (WDM) couplers for both multimode and single mode fibers. These WDM couplers currently have about 20 dB crosstalk from port 2 to port 1. NEC engineers are going to experiment with the insertion of a filter at port 2 to decrease crosstalk to 0.7 dB. Typical connection loss is 1.5 dB.

2.5.2.4 Integrated Optics and Optical Signal Processors

NEC researchers are actively engaged in work on electro-optical switches. A 4 x 4 matrix $LiNbO_3$ directional coupler switches at 21 volts with -30 dB crosstalk. While insertion loss is high at 7 dB, the switch operates up to

30 MHz, making it suitable for high definition TV applications. The switch incorporates a Ti-diffused optical waveguide. A new type of waveguide under development uses a double diffusion of Ti followed by Mg in the $LiNbO_3$ substrate. It is expected that this new, more circular waveguide will reduce the insertion loss by 3 or 4 dB.

NEC is also working on a high speed integrated optical spectrum analyzer (IOSA) which incorporates a laser diode, surface acoustic wave (SAW) device, and a CCD array detector on a $LiNbO_3$ substrate. The analyzer has a dynamic range of 28 dB, a frequency bandwidth of 200 MHz, and a frequency resolution of 4 MHz. Current efforts are directed at improving the dynamic range to 35 dB.

2.5.2.5 Surface Acoustic Wave (SAW) Devices

NEC researchers are developing SAW delay lines, SAW convolvers, and SAW bandpass filters. For short delay times, an inter-digital transducer (IDT) is relatively easy to fabricate. For long delay times, conventional reflective array compressor (RAC) delay lines require a two step fabrication process involving photolithography for the transducer and ion milling for the reflector. Photolithography is used to fabricate both the transducer and reflector of NEC's metal strip RAC, at about one-half the cost of a conventional RAC.

A SAW convolver is typically limited by substrate size to about 20 μsecs integration time. NEC has developed a curved convolver using a U-shaped SAW waveguide with a 2 cm radius to increase the integration time to 38 μsecs. The center frequency input signal is 300 MHz and output signal is 600 MHz. The convolution efficiency is -80 dBm. A prototype system was begun in 1983.

Using an inter-digital transducer (ITD) structure, NEC has developed a SAW multi-channel filter. Operating at 200 MHz, this 5 channel filter has 2 MHz bandwidth and better than 35 dB off-band rejection.

2.6 FUJITSU LIMITED

2.6.1 Company Background

Established in 1935 out of the Communications Division of Fuji Electric Co., Ltd., Fujitsu Limited today is Japan's top computer manufacturer and one of the world's leading manufacturers of telecommunications systems and equipment. Fujitsu's capacity to produce semiconductors has increased from a small, captive corporate supplier, to now being a major producer of semiconductors. Corporate sales in the fiscal year ending March 31, 1986 exceeded $8 billion. Computer sales accounted for 72%, communications systems for 16%, and electronic devices for 12% of all sales. Fujitsu's total corporate research and development budget is equal to about 10% of sales.

Fujitsu currently employs 55,000 people at 12 plants and 2 main research laboratories. These labs are the Fujitsu Information Processing Systems Laboratory, established in 1970 to provide research and development in computer technology, and Fujitsu Laboratories, Ltd., established in 1968. Fujitsu Laboratories serves as Fujitsu's main center of R&D and has some 1200 employees. These people are about equally divided between their Kawasaki and Atsugi facilities. Work at the Kawasaki Lab is primarily in computer-related systems (e.g., computer assisted learning, and medical electronics). The Atsugi Lab, opened in June of 1983, covers about 24,520 m^2, of which 1/5 (4,904 m^2) is clean room. This Lab carries out research in telecommunications systems, space electronics, electronic devices, and materials. Research funding is about 1.3% of sales at these two facilities.

2.6.2 Research Activities and Key Technologies

The Semiconductor Laboratory at Atsugi is engaged in work on Silicon (Si) integrated circuits (ICs), Gallium Arsenide (GaAs) ICs, optical devices for fiber optic communications, and infrared (IR) detectors. They are currently working on 4 Mbit memory chips in silicon. The high electron mobility transistor (HEMT) was developed here by Dr. T. Mimura in 1980. Work continues on HEMT as well as HBT and FET devices. LSI levels in GaAs have been achieved

with the development of a 4k SRAM. In fiber optic communication systems, the Lab is developing a 400 Mbps optical fiber system with NEC. They are also working on a system to connect Japan, Hawaii, the continental United States, and finally the United Kingdom in a joint-venture with Nippon Telephone & Telegraph and American Telephone & Telegraph. This work involves the development of undersea electro-optic cable with a lifetime greater than 10^6 hours. The IR work is in the 3-5 μm wavelength region primarily using mercury-cadmium-telluride (HgCdTe or MCT) material. The following sections give details of these and other topics that Fujitsu personnel discussed with the team.

2.6.2.1 Fiber Optic Communications

Building on their 400 Mbps optical transmission system (OTS), Fujitsu researchers have developed a new system that multiplexes four 400 Mbps channels to give a transmission speed of 1.6 Gbps. This 1.3 μm wavelength OTS will use repeaters every 10 to 20 km. The repeaters, which should go into production next year, consist of 9 ICs in an 8 layer package measuring 30 x 24 mm with 36 pins. This multi-layer package is designed for the 1.6 Gb transmission speed. Amplifier gain is 53 dB, the dynamic range is 26 dB, and the bandwidth is .94 GHz. The system will use a distributed feed-back (DFB) laser diode (LD) with a lifetime greater than 100 years as its source and a GaInAs avalanche photodiode (APD) as its detector. The system error rate was reported to be less than 10^{-11}.

Fujitsu researchers are currently working on both transmitter and receiver opto-electronic integrated circuits (OEIC). They are in early developmental stages on a number of devices. One of these devices incorporates a PIN (P-intrinsic-N) photodiode (PD) and a 4 field effect transistor (FET) amplifier on a GaAs substrate. Other devices incorporate laser diodes (LD) with FETs. These devices offer the advantages of light weight, small size, high speed operation, high reliability, and low cost fabrication.

Since the temperatures needed to fabricate diodes and FETs are not compatible, Fujitsu engineers have developed an experimental two-step process to first

fabricate the laser or photodiode by liquid phase epitaxy and then add the FET structures by molecular beam epitaxy (MBE). While this process has proven successful, so far, yields have been extremely low. Eventually, it is expected that metal organic chemical vapor deposition (MOCVD) will be used for commercial production instead of MBE.

2.6.2.2 Laser Diodes

Much of Fujitsu's laser diode R&D is directed at remote repeater applications for optical fiber communications systems. They currently have developed a 1.3 μm V-groove substrate buried heterostructure (VSB) laser which operates at 70° C and 5 mW forward current. This semiconductor laser saturates after the first few thousand hours of operation producing a device with very stable output and a long lifetime. Chemical etching with holographic masking is used to make the corrugation layer on an InP substrate.

Research also is proceeding on lower loss, 1.5 μm distributed feedback (DFB) lasers.

2.6.2.3 Plasma Displays

Fujitsu is producing plasma displays in formats for personal computers (640 x 400 pixels) and for banking terminals (320 x 80 pixels). These displays feature a black dot matrix, are flickerless, produce 50 ft-Lamberts brightness, have high 20:1 contrast ratios and greater than 10,000 hours operating life. These displays have a pitch of 0.33 mm, a drive voltage of 30 volts, and use only 20 watts of power. The units cost about 70,000 yen.

Researchers are developing a surface discharge, color display. Instead of putting phosphor particles between MgO layers as is conventionally done, this display has separate phosphor and discharge sites.

2.6.2.4 GaAs Metal Semiconductor Field Effect Transistors (MESFETs) and High Electron Mobility Transistors (HEMTs)

Fujitsu researchers invented and developed the high electron mobility transistor (HEMT) in 1980. They are currently working on improved HEMTs and MESFETs and on achieving large-scale-integration (LSI) levels incorporating these devices.

One HEMT circuit, which became commercially available in March 1986, is an ultra low noise amplifier. This 20 GHz, four stage amp operates at 8 dB gain with 1.8 dB noise figure. At 4 GHz the noise figure falls to 0.4 dB. Another device is a self-aligned, enhancement-depletion mode (E-D) HEMT. Under test conditions it has operated twice as fast as a MESFET, and ten times faster at 77° K. Also under development are a 1k SRAM with 0.9 nsec access time and a 4k SRAM with 26k HEMTs and a 2 nsec access time. Fujitsu is producing HEMTs on three inch wafers at LSI levels. They have achieved full wafer threshold deviation voltage of 16 mV, and short range deviation of 6 mV. (Short range is used here as that range appropriate to MSI dimensions.)

LSI level MESFETs are also in pilot production. Both 10k and 26k gate arrays are under development. A 16K SRAM with 26k self-aligned GaAs MESFETS was said to be recently transferred to production.

2.6.2.5 Microwave Modules and MMICs

Fujitsu engineers have developed a number of power FETs. One is an on-chip, matched 4 W, 14 GHz device. Using air bridges and plated heat sinks, this FET uses a tree type gate feed structure. The device has 11 mm gate widths and 0.75 μm gate lengths. In X-band Fujitsu has produced a device with 12 W output and 8 dB gain. A newly developed device operates in C-band (3.7 - 4.2 GHz) at 14 W output.

An active 128 element phased array is also under development. Each module or element is self-contained producing 160 mW output power. This hybrid technology uses diode switched line phase shifters.

Other hybrid work includes an 8-18 GHz, 500 mW amplifier and an ultra broad band, distributed traveling wave type amplifier.

2.6.2.6 HgCdTe Materials and Charge Coupled Device (CCDs)

Fujitsu has been developing detectors since 1960 when their primary materials were InSb and extrinsic Ge. Mercury-Cadmium-Telluride (MCT or HgCdTe) has been used since 1968. Liquid phase epitaxy (LPE) has been used to grow MCT since 1977. Metal organic chemical vapor deposition (MOCVD) work was begun in 1983. Researchers are currently using molecular beam epitaxy (MBE). Using these growth techniques, they are producing a variety of PC arrays at 3 to 5 and 10 μm wavelengths. Current bulk material is inadequate for PV IRCCD applications however.

Fujitsu is now conducting R&D on PV 64 x 64 element and linear hybrid arrays. The 64 x 64 element, 3 to 5 μm array is coupled with a Si multiplexer.

A commercially available PC, 16 element linear array camera operates at 200° K and has a three stage, thermoelectric (TE) cooler. The camera is a mirror scanned system.

2.7 JAPAN AVIATION ELECTRONICS (JAE)

2.7.1 Company Background

JAE is a relatively small high technology company, founded in 1953, which reported $400 million in sales last year. Of their 3,000 employees, 400 are engineers designing equipment. Primary product lines include connectors, relays, circuit breakers, switches, panel switches, inertial navigation systems and sensors, flight control systems and radar altimeters. JAE has a history of joint-ventures with U.S. companies. Figure 15 lists some of these companies and their projects.

COMPANY	PROJECT
General Electric	F4E and F15J flight control system
Hamilton Standard	Flight stabilization systems for ASW helicopters
Honeywell	F-104 flight control system
	Radar Altimeter
	Accelerometers for Boeing 757 & 767
Teledyne Avionics	No Project Specified
Gould	No Project Specified

Figure 15

JAE-U.S. JOINT VENTURES

JAE uses a high degree of industrial automation in the manufacturing and testing of their products. Tests include vibration, heat, water, oil, and radiation. The major product line accounting for 75% of sales, consists of electronic components such as switches and connectors.

2.7.2 Research Activities and Key Technologies

JAE major research thrusts are in inertial navigation and guidance systems; inertial sensor technologies such as gyros, accelerometers, and ring laser gyros; automatic flight control systems including auto stabilization, yaw dampers, and fly-by-wire-control configured vehicles; and microwave technology for radar altimeters. They also are developing LCD panels for cockpit applications.

2.7.2.1 Laser Inertial Navigation Systems & Laser Gyros

Inertial navigation systems include several conventional gyros in routine production for aircraft, missile, torpedo and helicopter applications. JAE also produces one-axis accelerometers. JAE is developing several RLGs of their own. One system will be space qualified for use in the NASDA H-2 rocket.

2.7.2.2 Fiber Optic Gyros (FOG)

JAE is developing fiber optic gyros. Their objective is to develop three grades of FOGs. The first is a moderate device with an accuracy of 100°-1000°/hr. The second is a tactical grade FOG with an accuracy of 0.1°-10°/hr. It is currently in the brass-board development phase. The third, inertial grade FOG will have an accuracy better than 0.01°/hr.

This overall development program is aimed at the production of a rigid, small, light weight, highly stable, low cost optical circuit with a light source module, coupler, and integrated optics. The signal processing circuit will have a wide dynamic range and have effective error compensation.

The major problems to be overcome include the stability of components and the development of the signal processing circuit. Also, JAE is currently using .83 μm superluminescent diodes (SLDs) as their light source which are purchased from the U.S.

2.7.2.3 Flat Panel Displays

JAE is currently developing third generation, LCD color flat panel displays for U.S. companies. They have no interest in commercial TV markets, and are only working on cockpit display systems. The current (1985) model measures 5 x 5 inches, has 120 dots/inch, and displays 8 colors. It incorporates a .4 inch resolution touch switch. The next generation model will measure 6.7 x 6.7 inches, have 150 dots/inch, and also display 8 colors.

3.0 ASSESSMENT AND SIGNIFICANCE

3.1 ELECTRO-OPTICS TECHNOLOGIES

Japan's strength in electro-optics (EO) lies in their capabilities to commercialize EO research developments. They have been particularly successful in the development of coherent and incoherent light sources, fiber-optics, fiber-optic couplers, optical storage and readout technology, high resolution displays, and visible CCD imagers for TVs. They are not as advanced as the U.S. in the development of focal plane arrays.

Diode light source and detector developments are driven by two primary applications in Japan. One area is fiber optic communications. Typical Japanese devices in production are similar to those being developed in the U.S. The Japanese are working at 1.2 to 1.3 μm wavelengths at 200 mW power and 70% efficiency and at 1.47 to 1.55 μm wavelengths at 100 mW power and 60% efficiency for a number of fiber optic communication systems. Various companies are using both liquid phase epitaxy (LPE) and metal organic chemical vapor deposition (MOCVD) to fabricate these diodes.

The other application driving EO development in Japan is optical storage read and write devices. These devices are used in commercial products such as compact disc and video disc players, and office automation systems. Older 0.83 μm, 80 mW devices are beginning to be replaced by higher resolution (and therefore greater information capacity) 0.67 μm, 100 mW laser diodes.

Japanese companies are producing low cost charge coupled device (CCD) imagers and focal plane arrays for consumer and commercial TV camera applications. CCD imagers for visible applications are typically 128 x 128 arrays of 10 x 10 μm detectors. Several companies offer a range of CCD cameras for commercial markets. IR cameras for building security and automated quality control applications use PtSi and MCT (HgCdTe), 3 to 5 μm, focal plane arrays. Chip size for 512 x 512 element arrays is typically 12 x 16 mm.

In the area of display technology, the Japanese are concentrating in three major areas. These areas are improved cathode ray tubes (CRTs), plasma display panels (PDPs), and liquid crystal display (LCD) flat panels. All three areas are undergoing vigorous R&D and commercialization at various companies. Some of these devices include:

- 1800 ft-Lamberts, 109 x 82 mm high brightness INDEXTRON CRT.
- 20" x 20", 2048 x 2048 pixel flat CRT for computer & flight control monitors.
- 640 x 400 pixel, 50 ft-Lamberts plasma display panel using low voltage (30 V) and long life (>10,000 hours) typical.
- 5" x 7" single color plasma display panel using thin-film transistors has 20 ft-Lamberts brightness.
- 3 color surface discharge device in R&D. Estimated 2 years to production.
- 5" x 5", three color liquid crystal display with 120 dots/inch resolution in prototype production for aircraft cockpit applications.

Other electro-optic-related technologies which are under extensive research and development in Japan include fiber optic gyros, ring laser gyros, optical processing devices, and fiber optic local area network components and technology. Several companies demonstrated strong interest in hybrid/monolithic integrated circuits incorporating optical and digital components in both Si and GaAs.

3.2 MILLIMETER WAVE AND MICROWAVE TECHNOLOGIES

Driven by the growing demand and rapid expansion in consumer oriented microwave devices, especially cellular radios and direct broadcast satellite

(DBS) receivers, all of the major Japanese electronics companies are actively engaged in device development and research. These commercial communication related applications operate at frequencies under 30 GHz. Rapid progress is being made at a number of companies on wide-band, low noise, and high power amplifiers, multivibrator and dielectric stabilizing cavity oscillators, dual gate FET and balanced diode mixers, phase shifters and switches, frequency dividers, and multifunction monolithic microwave integrated circuits (MMICs).

Advances in GaAs IC technology has resulted in the development of general purpose wideband amplifiers for 1-2 GHz mobile radios, 1.6 Gbps data rate optical communication systems, 3 GHz phased array radars, intermediate frequency amps, and UHF-VHF televisions. Low noise amplifiers are of interest because of their importance in DBS receivers. Power amplifier development is geared toward satellite system application. With less consumer demand for power amps in Japan, development of these devices lags that in the U.S.

Oscillators, mixers, and frequency dividers all have applications in communications systems. Multifunction circuits such as signal generators are being developed at several companies.

Computer applications are the driver of Japan's intense efforts to develop faster, smaller, and more efficient devices. Research is aimed at increasing circuit speed in both silicon bipolar and compound semiconductor devices. Further, monolithic integration of both microwave linear and very fast digital circuits with optoelectronic devices, such as lasers, LEDs, and detectors is also being intensively investigated for applications in wideband communication systems. There is also a strong effort in Japan on heterostructure epitaxy leading to promising results in silicon-on-insulator (SOI) and GaAs-on-Si materials technologies.

Examples of some of these devices obtained from the trip and technical literature include:

- 14 GHz, 4W power field effect transistors (FETs), with 4W output, 0.75 μm gate length, 11 mm gate width.
- X-band, 2 stage, 4 FET, low noise amplifier (LNA) with 3.5 dB noise figure and 17 dB gain.
- 5 chip, 4 stage GaAs FET amplifier.
- 10 mW 5°, 12°, and 180° FET phase shifters.
- K_a-band, 3 x 2 mm monolithic device for satellite application with 13 GHz input and 26 GHz output in R&D.
- 30 GHz, K_a-band, power amp has 1W output with 3 dB gain from 27 to 28 GHz, and measures 2.1 x 1.4 mm.
- One-stage FET amp with 0.7 μm gate length and 150 μm gate width, measuring 2 x 2.5 x .2 mm, with 3.5 dB noise figure from 11.2 to 12.6 GHz.
- 12 GHz, one-stage low noise amp with 2.5 dB noise figure and 9.5 dB gain at 11.7 to 12.7 GHz, measures 1 x 0.9 mm.
- 12 GHz, two-stage low noise amp using closely space electrode FET structure fabricated by ion implantation, has 0.5 μm gate length, source-to-gate and drain-to-gate spacing of 0.5 μm, measures 1.5 x 0.9 mm, with 2.8 dB noise figure and 16 dB gain over 11.7 to 12.7 GHz.
- 4 GHz band two-stage FET amplifier with 1 μm gate length, source-to-gate and drain-to-gate spacing of 0.5 μm, first stage gate width of 1000 μm, second stage gate width of 500 μm, -0.6V threshold voltage, 3 dB noise figure, 170 mW power dissipation,

- 28 GHz power amp with 3.7 dB gain, 21.1 dBm output power at 1 dB gain compression point, 8% efficiency, and measures 1 x 1.3 mm.

- 12 GHz, low noise FET amplifier with 0.7 μm gate length and 1.5 dB noise figure.

- 50 MHz to 2 GHz low noise amplifier with 10 dB gain and 2 dB noise figure.

- 50-1000 MHz, 3 stage low noise amplifier with 27 dB gain and 2 dB noise figure.

- UHF mixer with 5 dB conversion gain.

- 12 GHz, dual gate, FET mixer.

A notable exception to this commercially driven work is the continued development of a 94 GHz seeker head begun in 1984 at MELCO. Current R&D is aimed at reducing the receiver size.

These developments are complemented and enhanced by related work in GaAs and other III-V compound material and processing technology. Excellent progress has also been made in high electron mobility transistor (HEMT) and other advanced structure devices, in integrating optical and digital devices, and improving digital technology.

Japanese companies are engaged in extensive research and development of advanced microelectronics and digital integrated circuits (IC). The majority of GaAs digital ICs currently in production are comparable to U.S. levels. These devices incorporate sub-micron design rules, specialized gate metals (such as tungsten-aluminum) for higher reliability, deep ultra-violet (UV) (250 nm wavelength range) lithography, and typically have 80 to 300 gates per chip. 4k static random access memory (SRAM) circuits are just entering production in Japan, a little ahead of the U.S. 64k GaAs SRAMs are expected to move from R&D to pilot production within the next 12

months. During the team's visit in August, Japanese news agencies announced that Japanese microelectronics companies had just begun commercial production of GaAs digital large scale integration (LSI) circuits. The U.S. has not yet reached LSI levels in production.

The team also observed 1 megabit silicon dynamic random access memory (DRAM) circuits in production at several companies and extensive R&D on 4 megabit DRAMs, also in silicon.

4.0 OVERALL PERSPECTIVES

4.1 CONCLUSIONS

This trip was very successful in that the EO/MMW/MW Team accomplished its mission of initiating dialog with the Japanese government and Japanese industries. Further, it was determined that a significant number of Japanese industries have ongoing R&D programs in EO, MMW, and MW related activities that are of interest to, and offer potential for, DoD programs. Preliminary analysis grouped these EO/MMW technologies into:

- INFORMATION PROCESSING, including fiber optics, television, displays, communications, and computers;

- BASIC MICROELECTRONICS, including GaAs devices and optoelectronics (specifically IR detectors and arrays);

- SPACE APPLICATIONS, including ring laser and fiber optic gyros; and

- AERONAUTIC APPLICATIONS, including radar altimeters, accelerometers, and various display and control technologies.

The Japanese are demonstrating impressive and rapid progress in these areas, particularly in transitioning R&D work into production and commercialization.

During the course of this trip, a number of technology areas with particularly high potential for application in U.S. programs were identified. Of special note were the observations that:

- Japanese industries appear to be within 1-2 years of commercialization of magneto-optical erasable disk technology for mass storage applications.

- Several Japanese companies demonstrated hybrid and monolithic integration of optical and digital devices. This work, and interfacing of GaAs and silicon devices will enable the next generation of advanced electronics and electro-optics.

- Japanese industries continue to develop a base of GaAs devices (HEMT, LSI MESFETs, power FETs, gate arrays, etc.) which are comparable or ahead of U.S. work. Their approach of developing more generic devices rather than highly specialized circuits (as is done in the U.S.) has increased Japan's ability to produce devices at low cost and high volume. Their successes in these technologies are due, at least in part, to their high rate of investment in IR&D. Companies reported investments of 10% of total sales and better being spent on research.

- Low cost, high production of shutterable visible CCD imagers is state-of-the-art quality in Japan and could benefit U.S. military imaging applications.

- The Japanese are slightly ahead of the U.S. in the variety of their R&D of cathode ray tube (CRT), plasma display panel (PDP), and liquid crystal display (LCD) technologies and lead the U.S. in the commercialization and production of these devices.

During the July 1984 trip to Japan, the following observations were reported:

- Japan's millimeter-wave devices and components are comparable to those made in the U.S. Gallium arsenide and other III-V materials make broadband phased-array technology possible. Electro-optic technologies of interest include high-resolution visible CCD TV cameras and color imagers for low-cost surveillance systems.

- Japanese industry has attained world recognition for its ability to transfer research and development results into production capabilities. Electro-optic and millimeter-wave technologies have benefited from this ability. Parallel product development and emphasis on production engineering contribute to this success and to the low cost and high quality of electro-optic and millimeter-wave materials, components, and complete systems. All of the electro-optic and millimeter-wave development and production facilities visited had outstanding management.

- The Team observed that industrial and commercial interests drive 90-95% of all Japanese electro-optic technology. Millimeter-wave technology is driven to a lesser extent by commercial interests. This commercial motivation will necessitate extensive cooperation between the U.S. government and the Government of Japan to effectively interact with individual Japanese companies. Several U.S. industries are interested in Japan's very effective management techniques to transition technology from R&D to engineering and manufacturing for large scale production. The exchange of technology would provide improvements in system development for U.S. and Japanese products.

Figure 16 evaluates all 13 Japanese facilities visited by the EO/MMW Team and assesses each facility's strengths.

JAPANESE COMPANIES	AREAS OF INTEREST																							
	MICROWAVE/ MILLIMETER WAVE TECHNOLOGIES				ELECTRO-OPTICS						FIBER OPTICS				DISPLAYS			MICRO-ELECTRONICS			OTHER			
	Devices and Components (SAWS)	MMICs	GaAs Devices	DBS Receivers/Sat Comm & Nav	Devices and Components	Semiconductor Lasers	Optical Storage	Visible Imagers	IR CCD/Imagers	Seekers	Devices and Components	Fiber Optic Gyros	Ring Laser Gyros	FO Communication Devices	High Resolution CRTs	EL/Plasma Panels	Liquid Crystal Displays	GaAs Digital ICs	Si Digital ICs (VLSI)	MOCVD/MBE R&D	Advanced Robotics	Signal Processing	Artificial Intelligence	JJ (SQUIDS)
FUJITSU			X	X			X		X		X			X		X	X	X	X	X				
HITACHI				X		X	X	X	X		X													
JAE												X	X		X	X								
MATSUSHITA	X		X	X		X	X	X			X			X	X						X			
MELCO	X		X	X			X	X	X		X			X				X						
NEC	X			X	X			X	X			X						X	X	X				
OKI	X	X	X			X					X			X		X			X	X	X			
SHARP	X			X		X	X	X			X			X		X	X							
SONY				X		X								X	X			X		X		X		
SUMITOMO	X		X			X					X	X								X				
TOSHIBA	X		X	X		X		X	X		X			X										
TRDI#1						X		X	X															
TRDI#3	X		X						X			X												

Figure 16

X = COOPERATION POTENTIAL

Source: FO/MMW Team

APPENDIX A

1984 JAPAN TRIP SUMMARY

SUMMARY OF FINDINGS

JAPANESE ELECTRO-OPTIC AND MILLIMETER WAVE R&D

1984 JAPAN TRIP

OVERVIEW

In January 1983, the Japanese government, headed by Prime Minister Nakasone, decided to extend Japan's defense cooperation by offering the release of military technologies to the U.S. A framework for the transfer of military technologies from Japan was established in November 1983 when the U.S. and Japan exchanged notes on the transfer of military technology. The notes provided an overall framework for the transfer of Japanese military technologies with potential benefit to U.S. defense capabilities.

As part of ongoing efforts to support this agreement, the Office of the Under Secretary of Defense for Research and Engineering (OUSDRE) proposed the creation of teams of DoD scientists and engineers to identify U.S. requirements, research Japanese technology programs, and visit key Japanese facilities and counterparts to identify technological areas for potential cooperation programs of mutual U.S. and Japan benefit.

The first Technology Team was created to review Japanese programs in electro-optics (EO) and millimeter-wave (MMW) technologies; investigate technological areas of interest; study mechanisms of technology transfer and modes of cooperation; and recommend structures for future reviews and further data exchanges. The eleven Technology Team members were selected for their expertise. (Brief biographies are provided in Appendix A.)

Dr. John MacCallum
Team Leader, DoD/OUSDRE
Mr. George Nicholas, DoD/OUSDRE
Dr. Sam Musa, DoD Consultant
Dr. Thomas Hartwick, DoD Consultant
Dr. Barry Spielman, NRL
Dr. Patrick McDermott, DoD Consultant
Mr. Charles Freeman, NVEOL
Dr. John Kuno, DoD Consultant
Dr. Anthony DeMaria, DoD Consultant
Dr. Ken Ando, DARPA
Dr. Ronald Paulson, AF Wright Aeronautical Labs

The Team met five times to outline project objectives, to be briefed by experts on Japan, to discuss previously published work on Japanese electro-optic and millimeter-wave technologies, and finally to select sites for visits and draft questions for Japanese counterparts. The Team's efforts were culminated by a trip to Japan from the 9th to the 20th of July 1984 to visit facilities and counterparts previously identified. This report is based on the findings and recommendations which came out of those meetings and the trip.

The Team was successful in initiating dialogue on technology exchange. A number of electro-optic and millimeter-wave technology activities of interest have been identified. These activities include not only items for purchase but also manufacturing methods and know-how, design and test data.

The Team found that, generally, while Japan lags in defense system development, Japanese management techniques are very effective at transitioning technology from research and development (R&D) to production phases. Figure A-1 shows a number of areas where the Technology Team observed EO/MMW technologies of interest. The marks (Xs) in Figure A-1 represent technologies observed or described in literature provided during the company visits.

FINDINGS AND CONCLUSIONS

The Electro-Optics and Millimeter-Wave Technology Team was successful in initiating dialogue on technology exchange with Japanese government and industry. They found all government and industry organizations to be very receptive to their visit and very interested in developing cooperative programs in electro-optic and millimeter-wave technologies, as well as other areas.

The Team observed that industrial and commercial interests drive 90-95% of all Japanese electro-optic technology. Millimeter wave technology is driven to a lesser extent by commercial interests. This commercial motivation will necessitate extensive cooperation between the U.S. government and the Government of Japan to effectively interact with individual Japanese companies. Several U.S. industries are interested in Japan's very effective management techniques to transition technology from R&D to engineering and manufacturing for large scale production. The exchange of technology would provide improvements in system development for U.S. and Japanese products.

MILLIMETER-WAVE AND MICROWAVE TECHNOLOGIES

Gallium-Arsenide Materials

Microwave and millimeter-wave quality gallium-arsenide (GaAs) materials are being produced and marketed in Japan. Five-inch-diameter wafers are under development, and current two- and three-inch-diameter wafers have defect densities typically $1 \times 10^4/cm^2$ to as low as $2 \times 10^2/cm^2$. Sumitomo produces over 30,000 microwave-quality GaAs wafers per month. This rate of production meets almost all of Japanese needs and more than half of worldwide needs.

GaAs materials are used in microwave and millimeter-wave FET devices, mono-lithic integrated circuits, and high-speed digital integrated circuits.

Devices and Components

The Japanese are actively engaged in the design, development, processing, and production of low-noise power FET devices up to 50 GHz. Several Japanese companies are in basic research and development phases on high electron mobility transistor devices. Japanese electronics companies have also produced IMPATT

Sites Visited by the Technology Team	MM-WAVE/µ-WAVE TECHNOLOGIES					E-O TECHNOLOGIES								
	GaAs Materials	Devices and Components	Systems	Active Apertures	DBS Receivers	Lasers	Optical Processing	Optical Data Storage	Visible Imager	Infrared Imager	Visible Night Vision Devices	LAN Components	Fiber Optic Gyros	Displays
TRDI #1						X			X	X	X			
TRDI #3		X	X	X						X			X	
NIPPON ELECTRIC COMPANY		X	X		X	X	X		X	X			X	
HITACHI					X	X		X	X	X		X		
FUJITSU	X	X	X		X			X		X		X		X
MITSUBISHI ELECTRIC COMPANY		X	X	X	X	X			X	X	X	X		X
TOSHIBA		X	X		X	X	X	X	X	X		X		
SHARP		X			X	X		X						
SUMITOMO	X	X				X						X	X	
MATSUSHITA		X	X		X	X	X	X	X			X		

FIGURE A-1

ORGANIZATION/TECHNOLOGY MATRIX

oscillators, Gunn local oscillators, antenna feeds, mixers, circulators, and SPST and SPDT switches suitable for microwave and millimeter-wave applications at engineering development levels.

These devices and components are being used more frequently in local area networks (LANs), Doppler and collision-avoidance radar, direct broadcast satellites, and radio astronomy.

Systems

Several important millimeter-wave and microwave systems are being developed in Japan. Radio astronomy (22-115 GHz) receivers and weather satellite efforts are in planning phases. X-band active-aperture seekers, IMPATT transmitter seekers, and 50-GHz local area networks are all in engineering development at various companies.

Direct Broadcast Satellite Receivers

Many of the electronics companies in Japan are currently marketing or plan to market DBS receivers. A high level of manufacturing automation is expected to produce high-volume, low-cost 12-GHz receivers. A monolithic integrated circuit approach is ready for transitioning into mass production.

ELECTRO-OPTIC TECHNOLOGIES

Lasers

All of the Japanese companies visited had extensive programs in laser diodes, and the quality of the technology was outstanding. Work was being done in CO_2, XeCl, YAG, lead salts, and Er:glass lasers. Programs existed in CO_2 lasers and YAG for material working, with moderate to little activity in Er:glass, lead salts, and XeCl lasers. Good work was being done in CO_2, XeCl, and lead salt lasers.

Laser technology was being applied in video disks, audio disks, data storage, printing, FO communications, semiconductor processing, material working, pollution detection, and time-domain reflectometry.

Optical Processing

Optical processing work was being carried out on a time-integrating acousto-optic correlator, an integrated optic acousto-optic spectrum analyzer (IO-AOSA), and Bragg cell development. Overall, however, few of the companies visited were working in the optical processing area, and generally a low level of effort was observed. Japanese commerical applications of optical processing are in general signal processing, Bragg cells, and radio astronomy. Japan continues the integrated optics approach to AOSA.

Optical Data Storage

In visits to several companies, the Technology Team found work on mature, commerical, high density (4×10^7 bits/cm^2), and permanent (archival) optical data storage. Work was in progress on erasable, high-density, and develop-

mental optical data storage. More than half of the companies visited had commercial products. Generally, the Team observed an excellent capability for producing commercial systems.

Visible Imager

The Technology Team found broadly-based multi-company efforts to develop single-chip color cameras for the world industrial and consumer marketplace. There is a major effort on linear arrays for document reading and facsimile applications. There is aggressive competition among the companies to develop a commercially viable chip. Hitachi is the first company in the world to produce a MOS camera in volume production. The depth and breadth of Japanese technology in this area is substantial. Commerical applications of the technology include high-volume, low-cost color cameras and facsimile equipment for the worldwide consumer/industrial markets.

Infrared Imager Technology

The Japanese are engaged in R&D work on IR detectors and arrays for domestic needs, including HgCdTe linear and area arrays, PT-SI Schottky barrier CCDs, and pyro-electric vidicons. First-rate research in HgCdTe and Schottky barrier imagers is being conducted in Japan.

Visible Night Vision Devices

The Japanese have done R&D work on fiber-optically-coupled image intensifiers, a low-light-level television (LLTV) imaging tracker, and active laser imaging radars (0.53, 1.06, 10.6 microns). The LLTV work is a single system built 2 years ago using French microchannel plate technology.

Fiber Optic Local Area Network (LAN) Component Technology

The Japanese are engaged in R&D work on components such as distributed feedback lasers at 1.3 and 1.55 microns, high-power 0.8 micron lasers, and integrated opto-electronic chips. Several companies are aggressively pursuing this topic for commercial purposes in the 30-200 MBPS range.

Fiber-Optic Gyro

Several companies are involved in fiber-optic gyro technology. Three approaches to the technology are: homodyne method (line sensor), frequency modulation, and heterodyne concepts. There is a development emphasis on improving accuracy. Industrial applications include autos and robots.

Displays

The Japanese are involved in R&D and production of electroluminescent (EL), liquid crystal (LC), and high-definition cathode ray tube (CRT) displays. They are leaders in EL and LC technology. They are the world leader in high-volume production of alphanumeric and graphic displays, and they are at the forefront in advanced imaging displays.

Commercial applications of alphanumerics include small calculators, intrumentation panels, etc. Graphics are applied in computers and map overlays, and imaging in flat panel TV sets.

SUMMARY

Japan's millimeter-wave devices and components are comparable to those made in the U.S. Gallium arsenide and other III-V materials make broadband phased-array technology possible. Electro-optic technologies of interest include high-resolution visible CCD TV cameras and color imagers for low-cost surveillance systems.

MANAGEMENT FINDINGS

Japanese industry has attained world recognition for its ability to transfer research and development results into production capabilities. Electro-optic and millimeter-wave technologies have benefited from this ability. Parallel product development and emphasis on production engineering contribute to this success and to the low cost and high quality of electro-optic and millimeter-wave materials, components, and complete systems. All of the electro-optic and millimeter-wave development and production facilities visited had outstanding management.

Electro-optic and millimeter-wave technology exchange between the U.S. and Japan presents distinct challenges. In Japan, much of the technology of interest to the U.S. is in the Japanese industrial sector. Furthermore, cultural, language, and political sensitivities are important considerations. The Japan Defense Agency (JDA) plays a primary role selecting companies for production of defense equipment and in formulating technology transfer for technologies developed for, and, therefore, owned by the Government. The Ministry of International Trade and Industry (MITI) is in charge of coordinating R&D policies for the technologies owned by the commercial sector and in regulating overseas technology transfer of them. An excellent working relationship between MITI and JDA personnel is a necessary component for a successful technology exchange.

The 8 November 1983 Exchange of Notes provides a new opportunity for significant technology exchange in electro-optic and millimeter-wave technologies as well as other fields. Substantial follow-up by DoD and U.S. industry is necessary if full advantage is to be taken of this new opportunity. Electro-optic and millimeter-wave related areas of interest are given in Figure A-2.

TECHNOLOGIES OF INTEREST

DESIGN/TEST DATA	PRODUCTION METHODS & KNOW-HOW	POTENTIAL SUPPLY SOURCE
• T/R MODULES	• BROAD-BAND PHASED ARRAYS	* • SOLID STATE IMAGER CHIPS
• LOCAL AREA NETWORKS (LAN)	• SEEKERS	• PIN/FET
* • OPTICAL DATA STORAGE	* • FIBER OPTIC LANs	* • LASER DIODES
• SEMICONDUCTOR LASERS	• FIELD EFFECT TRANSISTORS	• APD DETECTORS
* • DFB LASERS AT 1.3 micron	* • GaAs WAFERS	• E-O MATERIALS
• FIBER OPTIC GYROS	• IR FO WAVEGUIDES	* • HIGH DENSITY MEMORIES
• ACTIVE APERTURE SYSTEMS	* • LIQUID CRYSTAL DISPLAYS	• MICROWAVE & MMW COMPONENTS
• HIGH ELECTRON MOBILITY TRANSISTORS	* • ELECTRIC LUMINESCENT DISPLAYS	• GaAs WAFERS
* • HgCdTe	• LOW COST GYROS	
• SCHOTTKY BARRIER IR DEVICES	* • III-V MATERIALS	
• VOICE RECOGNITION & SYNTHESIS	• BARIUM-ZINC-TANTALUM COMPOUND MATERIALS	
• LITHIUM BATTERIES	• AUTOMATED MANUFACTURE OF EO MATERIALS & DEVICES	
* • LASER DIODES	• ERASABLE OPTICAL DATA STORAGE	
• LAN COMPONENTS	• MATERIALS FOR CO_2 LASERS	

* Technologies of High Interest.

FIGURE A-2

APPENDIX B

TEAM BIOGRAPHIES

BIOGRAPHIES

JOHN M. MACCALLUM, JR. - Team Leader

Staff Specialist for Surveillance, Communication, and Navigation, Office of the Under Secretary for Research and Engineering

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Ph.D. Electrical Engineering; Member Tau Beta Pi, Research Society of America; awarded Air Force Legion of Merit and Naval Research Laboratory Outstanding Performance Award; responsible for technical and budget analysis for Exploratory Development and Advanced Development in all military services in Surveillance, Avionics, and Communications technology; U.S. representative to NATO Defense Research Group on Infrared and Optics and U.S. National Leader for the Technical Cooperation Program (TTCP) (U.S., U.K., Canada, Australia, and New Zealand) on Infrared and Optics.

KEN ANDO

Program Manager, Strategic Technology Office, Defense Advanced Research Projects Agency (DARPA)

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Ph.D. Solid State Physics; American Physical Society, I.E.E.E., Society of Photo-Optical Instrumentation Engineering, and Sigma Pi Sigma Physics Honorary; two Letters of Commendation and one Professional Recognition Award for work with JPL and NASA. Published several papers on solid state and remote sensing topics; responsible for planning and managing the development of new and innovative concepts in technology areas important to the U.S. Department of Defense's space surveillance needs.

JAMES F. GIBSON

Director, Infrared Technology Division, U.S. Army Night Vision and Electro-Optics Center (NVEOC)

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Undergraduate, Physics; Graduate, Electrical Engineering, Physics; Optical Society of America, Arizona Academy of Science, American Mathematical Society, American Institute of Aeronautics and Astronautics, American

JAMES F. GIBSON (Continued)

Society for Testing and Materials; responsible for planning and directing Army infrared research and technology efforts; served as member and chairman of numerous Tri-Service committees and technical coordinating groups in areas of solid state lasers, image processing, and infrared technology.

MITCHELL B. MELLEN

Analyst, Science and Analysis Division, B-K Dynamics, Inc.

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M.S. Physics; specialist in Asian science and technology studies; served on government panels on technology transfer; papers presented on Technology Modernization in China.

Mr. Mellen supports components of the U.S. Government, including OSD, OUSDR&E, DoE, and Congress, analyzing scientific and technical development.

MARTIN MUSSELMAN

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Graduated from Susquehanna University with a BS degree and did graduate work at the University of Maryland. He joined the Naval Research Laboratory, Washington, D.C. where he served as an Electronic Scientist for 35 years. He was responsible for a wide area of research programs dealing with many types of electronic communications. He held a position with the Naval Material Command as Deputy to the Office overseeing all Navy research and development programs in electronics. His current assignment, again at the Naval Research Laboratory, is to manage special projects for Navy programs in fiber optics.

RICHARD L. REMSKI

Chief, Microwave Devices Group, Electro-Optics Technology Branch, Electronics Technology Division, Air Force Wright Aeronautical Laboratories

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B.S. and M.S. Physics, M.S. Engineering Managment; I.E.E.E., Electron Device Society, and Engineering Management Society; served on Electro-Optics and Microwave Working Groups of the Advisory Group on Electron Devices; participated in technology cooperation activities with the United Kingdom; participated in various research and development activities, including solid state lasers, microwave and millimeter wave power sources, electro-optics and information transmission; has directed exploratory development of GaAs and silicon RF power transistors, GaAs low noise transistors, and vacuum electronic RF power sources. Currently directs exploratory development of optically pumped, gas and solid state lasers, light modulators and control devices, focal plane arrays and other EO detectors.

BARRY SPIELMAN

Head, Microwave Technology Branch, Electronics Technology Division, Naval Research Laboratory

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Ph.D. Electrical Engineering; Member I.E.E.E. Microwave Theory and Techniques Society, Chairman of 15 national technical committees, member I.E.E.E. Microwave and Millimeter Wave Monolithic Circuits Symposium Steering Committee, Technology Program Committee for I.E.E.E. International Microwave Symposium. Responsible for planning, supervising, conducting, and administering fundamental and applied research in the general areas of microwave and millimeter-wave technologies.

APPENDIX C

GLOSSARY OF TERMS

GLOSSARY OF TERMS

Å - (Angstrom) A unit of linear measure equal to 10^{-10} meter.

Accelerometer - An instrument which measures acceleration or gravitational force capable of imparting acceleration. Used in many types of vehicles, ships, aircraft, and missiles.

AI - (Artificial Intelligence) The study and development of machines capable of reason by which they can learn functions normally associated with human intelligence.

AlGaAs - Aluminum Gallium Arsenide.

AlGaInP - Aluminum Gallium Indium Phosphide.

AlInGaP - Aluminum Indium Gallium Phosphide.

Alumina - (Aluminum Oxide) An inorganic insulator frequently used as a base substrate for hybrid film circuits because of its excellent electrical and physical properties.

APD - (Avalanche Photodiode) A photodiode operated in the avalanche breakdown region to achieve internal photocurrent multiplication, thereby providing rapid light-controlled switching operation.

ASW - Anti-Submarine Warfare.

Atsugi - Prefecture in Japan, not far from Tokyo.

Byte - Eight bits or binary units of information are grouped together to form a byte.

C-Band - The frequency band 3.7 to 4.2 gigahertz corresponding to wavelengths in the range of 3.7-5.1 centimeters.

CAD - (Computer-Aided Design) The generation of system designs and plans on a computer.

CAE - (Computer-Aided Engineering) The use of computer-aided design in the engineering specification of a device or structure.

CAM - (Computer-Aided Manufacturing) The use of computers to communicate work instructions to automatic machinery for the handling and processing required to produce a product.

CATV - (Cable Television) A television program distribution system in which signals from local and distant stations are picked up by high gain antennas, amplified on individual channels, then fed directly to individual receivers by underground or overhead coaxial cable.

CCD - (Charge Coupled Device) Semiconductor elements arrayed so that the electric charge at the output of one provides the input to the next.

Convolver - A surface acoustic wave (SAW) device in which signal processing is performed by a nonlinear interaction between two waves travelling in opposite directions.

CSD - (Charge Sweep Device) Mitsubishi Electric Company's term for a variation on a Charge Coupled Device.

Cz - (Czochralski) A crystal growing technique using a seed to produce large single crystals.

dB - (Decibel) A unit of measure describing the ratio of two powers or intensities, or the reference of a power to a reference power.

dBm - Measure of power equal to 10 times the common logarithm of the ratio of a given power to 0.001 watt.

DBS - (Direct Broadcast Satellite) A satellite capable of receiving a transmission and broadcasting it directly to a user without going through an intermediate receiver.

DCFL - (Direct Coupled FET Logic) Integrated circuit logic using field effect transistors and resistors, with direct conductive coupling between the FETs.

DDR - (Digital Data Recorder) A tape recording system for professional broadcasting applications using a rotating head scanner and digital encoding. Usually capable of recording very large amounts of data.

Demultiplexer - A device used to separate two or more signals that were previously combined by a compatible multiplexer and transmitted over a single channel.

Dewar - A vessel or container having double walls with the space between being evacuated to prevent the transfer of heat and the surfaces facing the vacuum being heat-reflective. Used to hold liquid gasses in low-temperature applications.

DF - (Dislocation-free) A crystal structure without defects along the lattice structure.

DFB - (Distributed Feedback) A type of semiconductor laser.

DoD - (Department of Defense).

Dopant - Impurities added to a semiconductor material to achieve desired characteristics such as n-type or p-type material.

DSB - (Double-Sideband) Amplitude modulation in which the modulated wave is composed of a carrier, an upper sideband whose frequency is the sum of the carrier and modulation frequencies.

DSP - (Digital Signal Processor) An electronic device that takes signals converted from analog to digital form and performs a variety of mathematical functions.

ECL - (Emitter Coupled Logic) A form of current-mode logic in which the emitters of two transistors are connected to a single current-carrying resistor so that only one transistor conducts at a time.

EE-LED - (Edge Emitting Light Emitting Diode).

ELIS - OKi Electric's name for their LISP-based computer.

EO - (Electro-Optics) The Class of devices and phenomena involving the influence of electric fields on optical phenomena.

Epilayer - A semiconductor layer having the same crystalline orientation as the substrate on which it is grown.

Epitaxy - Growth of one crystal on the surface of another crystal in which the growth of the deposited crystal is oriented by the lattice structure of the substrate.

ESS - (Electronic Switching System).

ETL - (Electric Technology Lab) A Laboratory run by the Japanese government, located in Tsukuba, involved in electronic research and development and artificial intelligence work.

Fabrey-Perot Interferometer - An interferometer having two parallel glass plates of variable separation with silvered inner surfaces so that incoming waves are multiply reflected between them.

FDM - (Frequency Division Multiplexing) A multiplex system for transmitting two or more signals over a common path by using a different frequency band for each signal.

FET - (Field-Effect Transistor) A transistor in which the resistance of the current path from source to drain is modulated by applying a transverse electric field between grid or gate electrodes; the electric field varies the thickness of the depletion layer between the gates, thereby reducing the conductance.

FIT - (Frame Interline Transfer).

Flickerless - Absence of random variations in the output current of an electron tube due to random changes in cathode emission in a range of a few cycles to a few tens of cycles per second.

FOG - (Fiber Optic Gyro).

Foot-Lamberts - A unit of luminance equal to $1/\pi$ candela per square foot.

FUJITSU - A major Japanese electronics and computer company.

GaAs - (Gallium Arsenide) A crystalline material made from elements 31 (Gallium) and 33 (Arsenic) with a melting point of 1238°C frequently alloyed with gallium phosphide or indium arsenide. One of the so-called III-V materials used as a semiconductor with forbidden-band gap of 1.4 electron volts and a maximum operating temperature of 400°C when used as a transistor. When used as a semiconductor laser, light is emitted at right angles to the junction region at a wavelength of 9000 angstroms.

GaInAs - Gallium Indium Arsenide.

Gb - (Gigabits) One million bits or binary units of information. A measure of data.

Gbps - (Gigabits per second) A rate of information transmission. One billion bits or binary units of information per second.

GBytes - (Gigabytes) One billion bytes or groups of eight binary units of information (bits). A measure of information.

Geostar - A Japanese communication and navigation satellite.

GHz - (Gigahertz) 10^9 cycles per second. A measure of frequency.

Gould - A major U.S. electronics company.

GPS - (Global Positioning Satellite) A U.S. communication and navigation satellite.

Gunn Diode - A microwave device which functions as an oscillator by developing a rapidly fluctuating current in a semiconductor such as n-type gallium arsenide when a constant voltage above a critical value is applied to contacts on opposite faces of the material.

HBT - (Hetero-bipolar-transistor) A type of field-effect-transistor.

HDTV - (High Definition Television).

HEMT - (High Electron Mobility Transistor) A very fast field-effect transistor using quantum effects.

HgCdTe	- (Mercury-Cadmium-Telluride) also MCT, a semicondctor material used in detecting infra-red radiation.
HIFET	- (Heterointerface Field Effect Transistor) Sony's name for a HEMT device.
Hitachi	- A major Japanese electronics firm.
IC	- (Integrated Circuit) A device of two or more circuit elements inseparably associated on or within a substrate such as silicon or gallium arsenide, to form an electrical network.
ICOT	- Abbreviation for the (Institute for New Generation Computer Technology) located in the Mitakokusai Building, Tokyo. Coordinates artifical intelligence and fifth generation computer research for Japan's Ministry of International Trade and Industry.
IDT	- (Inter-Digital Transducer) A circuit element used in surface acoustic wave devices as delay lines and filters. Two inter-locking comb-shaped metallic patterns applied to a piezo-electric substrate such as quartz or lithium niobate, converts between microwave voltages and surface acoustic waves.
IMPATT Diode	- (Impact Avalanche and Transit Time Diode) A pn junction diode with a depletion region adjacent to the junction, through which electrons and holes can drift, and is biased beyond the avalanche breakdown voltage. Used in an amplifier for an operating frequency range from 5 to 100 gigahertz primarily in the C and X bands, with power output up to 20 watts continuous wave or 100 watts pulsed.
Indextron	- Sony's high brightness television.
InGaAs	- Indium Gallium Arsenide.
InGaAsP	- Indiunm Gallium Arsenide Phosphide.
InGaP	- Indium Gallium Phosphide.
InP	- (Indium Phosphide) Metallic compound with semiconductor properties which melts at 1070°C.
InSb	- (Indium Antimonide) Crystals melt at 535°C; an intermetallic compound having semiconductor properties and the highest room-temperature electron mobility of any known material; used in hall-effect and magneto-resistive devices and as an infra-red detector.
IOSA	- (Integrated Optical Spectrum Analyzer) A thin-film device using optical components to measure the distribution of energy contained in frequencies emitted by light or other electromagnetic radiation.

IPC Laser - (Integrated Passive Cavity Laser) A semiconductor laser with a passive cavity resonator.

IR - (Infra-Red) Electromagnetic radiation whose wavelengths lie in the range from C 75 or 0.8 micrometer to 1000 micrometers.

IRCCD - (Infra-Red Charge Coupled Device) A charge coupled device operating in infra-red wavelengths.

JAE - (Japan Aviation Electronics) A Japanese electronics company specializing in aviation related components.

JDA - (Japan Defense Agency).

J-FET - (Junction Field-Effect Transistor) A field-effect-transistor in which there is normally a channel of relatively low-conductivity semiconductor joining the source and drain, and this channel is reduced and eventually cut off by junction depletion regions, reducing the conductivity, when a voltage is applied between the gate electrodes. Also known as a depletion-mode FET.

JVC - One of Matsushita's subsidiary electronic companies.

Ka Band - Designation for electromagnetic frequencies from 27 to 40 GHz.

Kbit - (Kilobits) One thousand bits or binary units of information. A measure of data.

Kword - (Kiloword) One thousand words. A measure of computer information.

LAN - (Local Area Network) A communications system for joining computers and/or other communications equipment.

LCD - (Liquid Crystal Display) A digital display that consists of two sheets of glass separated by a sealed-in, normally transparent, non-isotropic bire fringent material which exhibits interference patterns in polarized light. The outer surface of each glass sheet has a transparent conductive coating such as tin oxide or indium oxide, with the viewing-side coating etched into character forming segments with leads going to the display edges; a voltage applied between front and back electrode coatings disrupts the orderly arrangement of the molecules, darkening the liquid enough to form visible characters.

LD - (Laser Diode) A semiconductor laser in which stimulated emission of coherent light occurs at a pn junction when electrons and holes are driven into the junction by carrier injection, electron-beam excitation, impact ionization, optical excitation or other means.

LEC	- (Liquid Encapsulated Czochralski) A method for growing semiconductor crystals.
LED	- (Light Emitting Diode) A semiconductor diode that converts electric energy efficiently into spontaneous and non-coherent electromagnetic radiation at visible and near-infrared wavelengths by electroluminescence at a forward-biased pn junction.
$LiNbO_3$	- Lithium Niobate.
LMR	- (Low Molecular Resist).
LNA	- (Low Noise Amplifier) An amplifier with very low background noise when the desired signal is weak or absent.
LPE	- (Liquid Phase Epitaxy) A semiconductor crystal growth technique.
LSI	- (Large Scale Integration) An integrated circuit with more than 100 interconnected discrete devices on a single chip.
Magnetron	- A type of cross-field microwave tube producing microwave radiation in the 1-40 GHz frequency range.
Matsushita	- One of Japan's largest electronics company.
Mb or Mbit	- (Megabits) One million bits or binary units of information.
MBE	- (Molecular Beam Epitaxy) A technique of growing single crystals in which beams of atoms or molecules are made to strike a single-crystalline substrate in a vacuum, giving rise to crystals whose crystallographic orientation is related to that of the substrate.
MBPS	- (Megabits Per Second) A rate of information transmission. One million bits per second.
Mbyte	- (Megabyte) One million bytes or groups of eight binary units of information. A measure of information.
MCT	- (Mercury-Cadmium-Telluride) see HgCdTe.
Mecatronics	- A division of Sony's Atsugi Plant which makes printers and 3.5 inch disks.
MELCO	- (Mitsubishi Electric Company) A major electronics company in Japan.
MESFET	- (metal semiconductor field-effect-transistor).
MFLOPS	- (Million Floating-Point Operations) A measure of computer processing speed referring to millions of floating-point arithmetic operations per second.

MgO - Magnesium Oxide.

MIPS - (Million Instructions Per Second) An alternative measure of computer processing speed referring to millions of machine instructions per second.

MIPS - (Media Information Product Systems) A division of Sony's Atsugi Plant engaged in R&D of personal computers and automation systems.

MIS - (Metal-Insulator Semiconductor) Semiconductor construction in which an insulating layer, generally less than a micrometer in thickness, is deposited on the semiconducting substrate before the pattern of metal contacts is applied.

MITI - (Ministry of International Trade and Industry) A Japanese government organization similar to the U.S. Department of Commerce.

Mitsubishi - A very large Japanese corporation involved in electronics.

MMIC - (Monolithic Microwave Integrated Circuit) An integrated circuit designed to operate at microwave frequencies with elements formed in place on or within a semiconductor substrate, with at least one element being formed in the substrate.

MMW - (Millimeter Wave) Electromagnetic waves of wavelength from 1 millimeter to 1 centimeter corresponding to frequencies between 30 and 300 gigahertz.

MOCVD - (Metal organic chemical vapor deposition) A method of growing layers of different materials on a substrate.

MSI - (Medium Scale Integration) Solid-state integrated circuits having more than 12 gate-equivalent circuits.

Multichannel FET - A field-effect-transistor in which appropriate voltages are applied to the gate to control the space within the current flow channels.

mV - (Millivolt) A unit of potential difference or emf equal to one-thousandth of a volt.

mW - (Milliwatts) A unit of power equal to one-thousandth of a watt.

MW - (Microwave also μW) An electromagnetic wave of wavelength between 0.3 and 30 centimeters corresponding to frequencies of 1 to 100 gigahertz.

NASDA - (Nippon Aeronautic and Space Defense Administration) Japan's space organization analogous to the U.S. NASA.

NEC	- (Nippon Electric Company) A major Japanese electronics company.
NETD	- (Noise Equivalent Temperature Difference) The change in equivalent blackbody temperature that corresponds to a change in radiance that will produce a signal-to-noise ratio of 1 in an infra-red imaging device.
nf	- (Noise Figure) The ratio of the total noise power per unit bandwidth at the output of a system to the portion of the noise power that is due to the input termination, at the standard noise temperature of 290 K. Also known as noise factor.
nsec	- (nanosecond) A measure of time equal to one-billionth of a second (10^{-9}).
OA	- (Office Automation) Use of electronic computers and computing machines for clerical and office-related jobs including typing, filing, accounting, etc.
OCLI	- (Optical Coatings Laboratory, Inc.) A U.S. company specializing in optics.
Oki Electric	- A major Japanese electronics company.
Opto-electronics	- The branch of electronics that deals with solid-state and other electronic devices for generating, modulating, transmitting, and sensing electromagnetic radiation in the ultra-violet, visible, and infra-red portions of the spectrum.
OTS	- (Optical Transmission System) A communication system [illegible] optical fiber transmission lines and associated [illegible] components.
OUSDRE	- (Office of the UnderSecretary for Defense [illegible] Engineering) A component of the U.S. Department [illegible]
Panafile	- Matsushita's office automation document [illegible] marketed by Panasonic.
Panasonic	- A marketing subsidiary of Matsushita.
$PbLaTiO_3$	- (Lead Lanthium Titanium Oxide [illegible] pyroelectric thin-films [illegible] high detectivity and res[illegible]
$PbTiO_3$	- (Lead Titanium Oxide [illegible] used as a [illegible]

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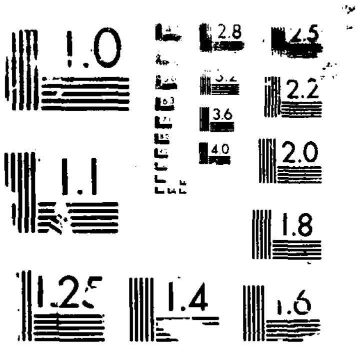
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

PCM - (Pulse Code Modulation) Modulation in which the peak-to-peak amplitude range of the signal to be transmitted is divided into a number of standard values each having its own three-place code; each sample of the signal is then transmitted as the code for the nearest standard amplitude.

PD - (Photodiode) A semiconductor diode in which the reverse current varies with illumination.

PD or PDP - (Plasma Display Panel) A display in which two sets of parallel conductors at right angles to each other are deposited on glass plates with the very small space between the plates filled with a gas; each intersection of two conductors defines a single cell that can be energized to produce a gas discharge forming one element of a dot matrix display.

Photo-Lithography - Photographically produced plates or masks are used in a resist and etching process to apply or remove layers of metal to fabricate an electronic circuit.

Photo-receiver - A component of an optical transmission system capable of detecting variations in light intensity or frequency and converting those variations into voltages.

PIM - (Parallel Inference Machine) A type of computer used in artificial intelligence research.

PIMOS - (Parallel Inference Machine Operating System) the operating system used on a parallel inference computer.

PIN Diode - (p^+-type-intrinsic-n^+-type diode) A diode consisting of a silicon wafer with nearly equal p-type and n-type impurities with additional impurities for each type at opposite ends. This leaves a lightly doped intrinsic layer in the middle which acts as a dielectric barrier between the n-type and p-type regions.

PN Junction - The interface between two regions in a semiconductor crystal that have been treated so that one is a p-type semiconductor and the other is an n-type semiconductor; it contains a permament dipole charge layer.

PNPN Diode - A semiconductor device consisting of four alternate layers of p-type and n-type semiconductor material with terminal connections to the two outer layers.

Preamp - An amplifier whose primary function is boosting the output of a low-level audio-frequency, radio-frequency, or microwave source to an intermediate level so that the signal may be further processed without appreciable degradation of the signal-to-noise ratio of the system.

Prescaler	- A scaler that extends the upper frequency limit of a counter by dividing the input frequency by a precise amount.
Prolog	- A computer language developed for artificial intelligence applications used extensively in Japan.
psec	- (picosecond) A unit of time equal to one-millionth of a microsecond or 10^{-12} second.
PSI Machine	- (Personal Sequential Inference Machine) A special computer used for artificial intelligence research.
PtSi	- Platinum Silicide.
Pyroelectric Material	- Crystals exhibiting the ability to produce a state of electrical polarity by a change in temperature.
RAC	- (Reflective Array Compressor) A component of a surface acoustic wave device comprised of a reflector and a transducer and acting as a delay line.
RAM	- (Random Access Memory) An integrated circuit data storage device having the property that the time required to access a randomly selected datum does not depend on the time of the last access or the location of the most recently accessed datum. Referred to as Dynamic RAM (DRAM) if data is lost at power down or static RAM (SRAM) if data is not lost.
RDSS	- (Radio Determination Satellite Service) A Japanese position determination, location, and navigation system developed by Sony.
Resistivity	- The electrical resistance offered by a material to the flow of current, times the cross-sectional area of current flow and per unit length of current path. The reciprocal of conductivity.
Responsivity	- Sensitivity to a particular parameter being detected.
RF	- (Radio Frequency) A frequency at which coherent electromagnetic radiation of energy is useful for communication purposes. The range from 10 kilohertz to 100 gigahertz.
RLG	- (Ring Laser Gyro) A gyro in which two laser beams travel in opposite directions over a ring-shaped path formed by three or more mirrors; rotation is measured by the interference pattern of the two beams.
ROM	- (Read Only Memory) An integrated circuit for storing data in permament, non-erasable form.

SAW - (Surface Acoustic Wave) A sound wave that propagates along and is bound to the surface of a solid. Devices such as filters, resonators, or oscillators, employ surface acoustic waves in the range 10^{-7}-10^{9} hertz, traveling on the optically polished surface of a piezoelectric substrate to process electronic signals.

SBFL - (Super Buffered FET Logic) A technique of interconnecting FETs.

Schottky Barrier Diode - A semiconductor diode formed by contact between a semiconductor layer and a metal coating; it has a nonlinear rectifying characteristic. Hot carriers are emitted from the transition region formed within the semiconductor surface and move to the metal coating that is the diode base; since majority carriers predominate, there are essentially no injection or storage of minority carriers to limit switching speeds. This results in a very fast switching diode.

SELFOC Lens - An NEC designed and patented lens for optical fiber couplers that is self focussing.

SHF - (Super High Frequency) The frequency band from 3,000 to 30,000 megahertz corresponding to wavelengths from 1 to 10 centimers.

SHG Devices - (Second Harmonic Generation Devices) An optoelectronic device utilizing the second harmonic of an input frequency.

SIMPOS - (Sequential Inference Machine Programming and Operating System) Operating system and programming language for a PSI artificial intelligence computer.

Sintered - A coherent bonded mass formed by heating metal powders without melting.

SiO - Silicon Oxide.

SLD - (Super Luminescent Diode).

Sony - A major Japanese electronics company.

SP - (Signal Processing) The amplification, filtering, extraction, measurement, and analysis of a signal's content or form.

SPST Switch - (Single Pole Single Throw Switch) A two-terminal switch on relay contact arrangement that opens or closes one circuit.

SSI - (Small Scale Integration) Integration in which a complete major subsystem or system is fabricated on a single integrated circuit chip. Usually no more than 1 to 10 devices.

Stirling Cooler - A refrigeration unit employing a regenerative thermodynamic power cycle using two isothermal and two constant volume phases.

Substrate - The physical material on which a microcircuit is fabricated.

Sumitomo - A Japanese electronics company.

Supercomputer - A computer capable of greater than 100 million instructions per second.

TASS - (Towed Array Sonar System) A specialized underwater acoustic system made up of a number of detectors working together.

Technics - A marketing subsidiary of Matsushita.

Toshiba - A major Japanese electronics company.

TPI - (Tracks Per Inch) A measure of information density on magnetic recording tape.

Transceiver - A radio transmitter and receiver combined in one unit using common circuitry for both functions.

Transimpedance Amp - An amplifier capable of converting optical signals to electrical voltages. Like ordinary impedance, transimpedance is measured in ohms. It is abbreviated Z_t.

Tsukuba - A city in Japan sometimes called the "Science Center."

ULSI - (Ultra Large Scale Integration) Experimental form of integrated circuit design with design rules measuring less than 0.5 micrometer and hundreds of thousands of gates per chips.

Undoped - The absence of impurities in a semiconductor material.

Uplink - The radio or optical transmission path upward from the earth to a communications satellite or aircraft.

USN - (United States Navy).

V - (Vanadium) The 23rd element on the periodic table. Used as a dopant to achieve high resistivity.

VCO - (Voltage Controlled Oscillator) An oscillator whose frequency of oscillation can be varied by changing an applied voltage.

VCR - (Video Cassette Recorder).

VHSIC - (Very High Speed Integrated Circuit) A U.S. government program to develop very fast, very small specialized devices for military systems.

VLBI - (Very Long BaseLine Interferometry) A method of improving angular resolution in the observation of two radio sources.

VLSI - (Very Large Scale Integration) Integrated circuit design incorporating sub-micrometer design rules and tens of thousands of gates per chip.

VSB - (V-groove Substrate Barrier) A V-shaped structure used in certain types of semiconductor lasers.

VTR - (Video Tape Recorder)

W - Tungsten

WDM - (Wave Division Multiplexing) A multiplexing technique which separates signals by wavelength.

Wideband - Property of a tuner, amplifier, or other device that can pass a broad range of frequencies.

X-band - The radio frequency band extending from 5200 to 10,900 megahertz, corresponding to wavelengths of 5.77 to 2.75 centimeters.

YAG Laser - (Yttrium-Aluminum-Garnet Laser) A four level infrared laser in which the active material is neodymium ions in a YAG crystal. Such lasers can produce output powers of several watts.

YIG Device - (Yttrium-Iron-Garnet) A filter, oscillator, parametric amplifier, or other device that uses an Yttrium-Iron-Garnet crystal in combination with variable magnetic fields to achieve wideband tuning in microwave circuits.

Zn - Zinc.

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